CHAPTER 1: INTRODUCTION TO VOLUME TWO

INTRODUCTION

Coastal habitats provide ecological, cultural, and economic value. They act as critical habitat for thousands of species, including numerous threatened and endangered species, by providing shelter, spawning grounds, and food (Mitsch and Gosselink 2000). They often act as natural buffers, providing ecological, social, and economic benefits by filtering sediment and pollution from upland drainage thereby improving water quality, reducing the effects of floodwaters and storm surges, and preventing erosion. In addition to these ecosystem services, healthy coastal habitats provide many human values including opportunities for:

- Outdoor recreation and tourism
- Education
- Traditional use and subsistence lifestyles
- Healthy fishing communities, and
- Obtaining other marketable goods

Therefore, healthy functioning coastal habitats are not only important ecologically, they also support healthy coastal communities and, more generally, improve the quality of human lives. Despite these benefits, coastal habitats have been modified, degraded, and removed throughout the United States and its protectorates beginning with European colonization (Dahl 1990). Thus, many coastal habitats around the United States are in desperate need of restoration and subsequent monitoring of restoration projects.

WHAT IS RESTORATION MONITORING?

The science of restoration requires two basic tools: the ability to manipulate ecosystems to recreate a desired community and the ability to evaluate whether the manipulation has produced the desired change (Keddy 2000). The latter is often referred to as restoration monitoring.

For this manual, restoration monitoring is defined as follows:

> "*The systematic collection and analysis of data that provides information useful for measuring project performance at a variety of scales (locally, regionally, and nationally), determining when modification of efforts are necessary, and building long-term public support for habitat protection and restoration*."

Restoration monitoring contributes to the understanding of complex ecological systems (Meeker et al. 1996) and is essential in documenting restoration performance and adapting project and program approaches when needs arise. If results of monitoring restored coastal areas are disseminated, they can provide tools for planning management strategies and help improve future restoration practices and projects (Washington et al. 2000). Restoration monitoring can be used to determine whether project goals are being met and if mid-course corrections are necessary. It provides information on whether selected project goals are good measures for future projects and how to perform routine maintenance in restored areas (NOAA et al. 2002). Monitoring also provides the basis for a rigorous review of the pre-construction project planning and engineering.

Restoration monitoring is closely tied to and directly derived from restoration project goals. The monitoring plan (i.e., what is measured, how often, when, and where) should be developed with project goals in mind. If, for example, the goal of a restoration project is to increase the amount of fish utilizing a coastal marsh, then measurements should be selected that can quantify progress toward that goal. A variety of questions about sampling techniques and protocols need to be answered before monitoring can begin. For the fish utilization example, these may include:

- Will active or passive capture techniques be used (e.g., beach seines vs. fyke nets)?
- Where and when will samples be taken?
- Who will conduct the sampling?
- What level of identification will be required?
- What structural characteristics such as water level fluctuation or water chemistry will also be monitored and how?
- Who is responsible for housing and analyzing the data?
- How will results of the monitoring be disseminated?

Each of these questions, as well as many others, will be answered with the goals of the restoration project in mind. These questions need to be addressed before any measurements are taken in the field. In addition, although restoration monitoring is typically thought of as a 'post-restoration' activity, practitioners will find it beneficial to collect some data before and during project implementation. Pre-implementation monitoring provides baseline information to compare with post-implementation data to see if the restoration is having the desired effect. It also allows practitioners to refine sampling procedures if necessary. Monitoring during implementation helps insure that the project is being implemented as planned or if modifications need to be made.

Monitoring is an essential component of all restoration efforts. Without effective monitoring, restoration projects are exposed to several risks. For example, it may not be possible to obtain early warnings indicating that a restoration project is not on track. Without sound scientific monitoring, it is difficult to gauge how well a restoration site is functioning ecologically both before and after implementation. Monitoring is necessary to assess whether specific project goals and objectives (both ecological and human dimensions) are being met, and to determine what measures might need to be taken to better achieve those goals. In addition, the lack of monitoring may lead to poor project coordination and decreased efficiency.

Sharing of data and protocols with others working in the same area is also encouraged. If multiple projects in the same watershed or ecosystem are not designed and evaluated using a complementary set of protocols, a disjointed effort may produce a patchwork of restoration sites with varying degrees of success (Galatowitsch et al. 1998-1999) and no way to assess system-wide progress. This would result in a decreased ability to compare results or approaches among projects.

CONTEXT AND ORGANIZATION OF INFORMATION

In 2000, Congress passed the *Estuary Restoration Act (ERA), Title I of the Estuaries and Clean Waters Act of 2000*. The ERA establishes a goal of one million acres of coastal habitats (including those of the Great Lakes) to be restored by 2010. The ERA also declares that anyone seeking funds for a restoration project needs to have a monitoring plan to show how the progress of the restoration will be tracked over time. The National Oceanic and Atmospheric Administration (NOAA) was tasked with developing monitoring guidance for coastal restoration practitioners whether they be academics, private consultants, members of state, Tribal or local government, non-governmental organizations (NGOs), or private citizens, regardless of their level of expertise.

To accomplish this task, NOAA has provided guidance to the public in two volumes. The first, *Science-Based Restoration Monitoring of Coastal Habitats, Volume One: A Framework* *for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000 (Public Law 160-457)* was released in 2003. It outlines the steps necessary to develop a monitoring plan for any coastal habitat restoration project. *Volume One* briefly describes each of the habitats covered and provides three matrices to help practitioners choose which habitat characteristics may be most appropriate to monitor for their project. Experienced restoration practitioners, biologists, and ecologists as well as those new to coastal habitat restoration and ecology can benefit from the step-by-step approach to designing a monitoring plan outlined in *Volume One*.

Volume Two, *Tools for Monitoring Coastal Habitats* expands upon the information in *Volume One* and is divided into two sections **Monitoring Progress Toward Goals** (Chapters 2-14) and **Context for Restoration** (Chapters 15-18). The first section, Monitoring Progress Toward Goals includes:

- Detailed information on the structural and functional characteristics of each habitat that may be of use in restoration monitoring
- Annotated bibliographies, by habitat, of restoration-related literature and technical methods manuals, and
- A chapter discussing many of the human dimensions aspects of restoration monitoring

The second section, Context for Restoration includes:

- A review of methods to select reference conditions
- A sample list of costs associated with restoration and restoration monitoring
- An overview of an online, searchable database of coastal monitoring projects from around the United States, and
- A review of federal legislation that supports restoration and restoration monitoring

The Audience

Volumes One and *Two* of *Science-Based Restoration Monitoring of Coastal Habitats* are written for those involved in developing and implementing restoration monitoring plans, both scientists and non-scientists alike. The intended audience includes restoration professionals in academia and private industry, as well as those in Federal, state, local, and Tribal governments. Volunteer groups, non-governmental organizations, environmental advocates, and individuals participating in restoration monitoring planning will also find this information valuable. Whereas *Volume One* is designed to be usable by any restoration practitioner, regardless of their level of expertise, *Volume Two* is designed more for practitioners who do not have extensive experience in coastal ecology. Seasoned veterans in coastal habitat ecology, however, may also benefit from the annotated bibliographies, literature review, and other tools provided.

The information presented in *Volume Two* is not intended as a 'how to' or methods manual: many of these are already available on a regional or habitat-specific basis. *Volume Two* does not provide detailed procedures that practitioners can directly use in the field to monitor habitat characteristics. The tremendous diversity of coastal habitats across the United States, the types and levels of impact to them, the differing scales of restoration activities, and variety of techniques used in restoration and restoration monitoring prevent the development of universal protocols. Thus, the authors have taken the approach of explaining *what one can measure during restoration monitoring, why it is important*, and *what information it provides* about the progress of the restoration effort. The authors of each chapter also believe that monitoring plans must be derived from the goals of the restoration project itself. Thus, each monitoring effort has the potential to be unique. The authors suggest, however, that restoration practitioners seek out the advice of regional experts, share data, and use similar data collection techniques with others in their area to increase the knowledge and understanding of their local and regional habitats. The online database of monitoring projects described in Chapter 17 is intended to facilitate this exchange of information.

The authors do not expect that every characteristic and parameter described herein will be measured, in fact, very few of them will be as part of any particular monitoring effort. A comprehensive discussion of all potential characteristics is, however, necessary so that practitioners may choose those that are most appropriate for their monitoring program. In addition, although the language used in *Volume Two* is geared toward restoration monitoring, the characteristics and parameters discussed could also be used in ecological monitoring and in the selection of reference conditions as well.

MONITORING PROGRESS TOWARDS GOALS

The progress of a restoration project can be monitored through the use of traditional ecological characteristics (Chapters 2 - 13) and/or emerging techniques that incorporate human dimensions (Chapter 14).

THE HABITAT CHAPTERS

Thirteen coastal habitats are discussed in twelve chapters. Each chapter follows a format that allows users to move directly to the information needed, rather than reading the whole text as one would a novel. There is, however, substantial variation in the level of detail among the chapters. The depth of information presented reflects the extent of restoration, monitoring, and general ecological literature associated with that habitat. That is, some habitats such as marshes, SAV, and oyster reefs have been the subject of extensive restoration efforts, while others such as rocky intertidal and rock bottom habitats have not. Even within habitats there can be considerable differences in the amount of information available on various structural and functional characteristics and guidance on selecting parameters to measure them. The information presented for each habitat has been derived from extensive literature reviews of restoration and ecological monitoring studies. Each habitat chapter was then reviewed by experts for content to ensure that the information provided represented the most current scientific understanding of the ecology of these systems as it relates to restoration monitoring.

Habitat characteristics are divided into two types: structural and functional. Structural habitat characteristics define the physical composition of a habitat. Examples of structural characteristics include:

- Sediment grain size
- Water source and velocity
- Depth and timing of flooding, and
- Topography and bathymetry

Structural characteristics such as these are often manipulated during restoration efforts to bring about changes in function. Functional characteristics are the ecological services a habitat provides. Examples include:

- Primary productivity
- Providing spawning, nursery, and feeding grounds
- Nutrient cycling, and
- Floodwater storage

Structural characteristics determine whether or not a particular habitat is able to exist in a given area. They will often be the first ones monitored during a restoration project. Once the proper set of structural characteristics is in place and the biological components of the habitat begin to become established, functional characteristics may be added to the monitoring program. Although structural characteristics have historically been more commonly monitored during restoration efforts, measurements of functional characteristics provide a better estimate of whether or not a restored area is truly performing the economic and ecological services desired. Therefore, incorporating measurements of functional characteristics in restoration monitoring plans is strongly encouraged.

When developing a restoration monitoring plan, practitioners should follow the twelve-step process presented in *Volume One* and refer to the appropriate chapters in *Volume Two* (habitat and human dimensions) to assist them in selecting characteristics to monitor. The information presented in the habitat chapters is derived from and expands upon the *Volume One* matrices (*Volume One* Appendix II).

Organization of Information

Each of the habitat chapters is structured as follows:

1. Introduction
    a. Habitat description and distribution
    b. General ecology
    c. Human impacts to the habitat
2. Structural and functional characteristics
    a. Each structural and functional characteristic identified for the habitat in the *Volume One* matrices is explained in detail. Structural and functional characteristics have generally been discussed in separate sections of each chapter. Occasionally, some functions are so intertwined with structural characteristics that the two are discussed together.
    b. Whenever possible, potential methods to measure, sample, and/or monitor each characteristic are introduced or readers are directed to more thorough sources of information. In some cases, not enough information was found while reviewing the literature to make specific recommendations. In these cases, readers are encouraged to use the primary literature cited within the text for methods and additional information.
3. Matrices of the structural and functional characteristics and parameters suggested for use in restoration monitoring
    a. These two matrices are habitat-specific distillations of the *Volume One* matrices
    b. Habitat characteristics are cross-walked with parameters appropriate for monitoring change in that characteristic. Parameters include both those that are direct measures of a particular characteristic as well as those that are indirectly related and may influence a particular characteristic or related parameter. Tables 1 and 2 can be used to illustrate an example. The parameter of salinity in submerged aquatic vegetation is a direct measure of a structural characteristic (salinity, Table 1). In addition, salinity is related to other structural characteristics such as tides and water source. Salinity is also related to functional characteristics such as biodiversity and nutrient cycling and may be appropriate to include in the monitoring of these functions as well (Table 2). Experienced practitioners will note that many characteristics and parameters may be related to one another but are not shown as such in a particular matrix. The matrices are not intended to be all inclusive of each and every possible interaction. The matrices provided and the linkages illustrated are only intended as starting points in the process of developing lists of parameters that may be useful in measuring particular characteristics and understanding some of their interrelationships.
    c. Some parameters and characteristics are noted as being highly recommended for any and all monitoring efforts as they represent critical components of the habitat while others may or may not be appropriate for use depending on the goals of the individual restoration project.
4. Acknowledgement of reviewers
5. Literature Cited

Three appendices are also provided for each habitat chapter. In the online form of *Volume Two,* these appendices download with the rest of the habitat chapter text. In the printed versions of *Volume Two*, each chapter's appendices are provided on a searchable CD-ROM located inside the back cover. Each appendix is organized as follows:

Appendix I - An Annotated Bibliography
a. Overview of case studies of restoration monitoring and general ecological studies pertinent to restoration monitoring
b. Entries are alphabetized by author

Parameters to Monitor the Structural Characteristics of SAV (excerpt)

Parameters to Monitor	**Biological**	Habitat created by plants	**Physical**	Sediment grain size[1]	Topography / Bathymetry	Turbidity	**Hydrological**	Tides / Hydroperiod	Water sources	Current velocity	Wave energy	**Chemical**	Nutrient concentration	pH, salinity, toxics, redox, DO[2]
Chemical														
Salinity (in tidal areas)								●	●					●

Table 1. Salinity is a parameter that can be used to directly measure a structural component of submerged aquatic vegetation habitats (Chemical/salinity). It is shown with a closed circle indicating that it highly recommended as part of any restoration monitoring program, regardless of project goals. A circle for salinity is also shown under the **Tides/Hydroperiod** and **Water source** columns as salinity levels are related to these structural characteristics as well. (Entire table can be found on page 9.39.)

Parameters to Monitor the Functional Characteristics of SAV (excerpt)

Parameters to Monitor	**Biological**	Contributes primary production	Supports biomass production	Provides breeding grounds	Provides nursery areas	Provides feeding grounds	Provides refuge from predation	Supports high biodiversity	Supports a complex trophic structure	Provides substrate for attachment	**Chemical**	Supports nutrient cycling	Modifies chemical water quality	Modifies dissolved oxygen
Chemical														
Salinity (in tidal areas)								❍				❍		

Table 2. Salinity is related to the functions of **Supporting high biodiversity** and **Supporting nutrient cycling**. It is shown here with an open circle, denoting that it may be useful to monitor if monitoring of these functions is important to the goals of the restoration project. (Entire table can be found on page 9.40.)

[1] Including organic matter content.
[2] Dissolved oxygen.

Appendix II - Review of Technical and Methods Manuals

These include reviews of:
a. Restoration manuals
b. Volunteer monitoring protocols
c. Lab methods
d. Identification keys, and
e. Sampling methods manuals

Whenever possible, web addresses where these resources can be found free of charge are provided.

Appendix III - Contact information for experts who have agreed to be contacted with questions from practitioners

As extensive as these resources are, it is inevitable that some examples, articles, reports, and methods manuals have been omitted. Therefore, these chapters should not be used in isolation. Instead, they should be used as a supplement to and extension of:

- The material presented in *Volume One*
- Resources provided in the appendices
- The advice of regional habitat experts, and
- Research on the local habitat to be restored

WHAT ARE THE HABITATS?

The number and type of habitats available in any given estuary is a product of a complex mixture of the local physical and hydrological characteristics of the water body and the organisms living there. The ERA Estuary Habitat Restoration Strategy (Federal Register 2002) dictates that the Cowardin et al. (1979) classification system should be followed in organizing this restoration monitoring information. The Cowardin system is a national standard for wetland mapping, monitoring, and data reporting, and contains 64 different categories of estuarine and tidally influenced habitats. Definitions, terminology, and the list of habitat types continue to increase in number as the system is modified. Discussion of such a large number of habitat types would be unwieldy. The habitat types presented in this document, therefore, needed to be smaller in number, broad in scope, and flexible in definition. The 13 habitats described in this document are, however, generally based on that of Cowardin et al. (1979).

Restoration practitioners should consider local conditions within their project area to select which general habitat types are present and which monitoring measures might apply. In many cases, a project area will contain more than one habitat type. To appropriately determine the habitats within a project area, the practitioner should gather surveys and aerial photographs of the project area. From this information, he or she will be able to break down the project area into a number of smaller areas that share basic structural characteristics. The practitioner should then determine the habitat type for each of these smaller areas. For example, a practitioner working in a riparian area may find a project area contains a *water column, riverine forest, rocky shoreline*, and *rock bottom*. Similarly, someone working to restore an area associated with a tidal creek or stream may find the project area contains *water column, marshes, soft shoreline, soft bottom*, and *oyster beds*. Virtually all estuary restoration projects will incorporate characteristics of the water column. Therefore, all practitioners should read *Chapter 2: Restoration Monitoring of the Water Column* in addition to any additional chapters necessary.

Habitat Decision Tree

A Habitat Decision Tree has been developed to assist in the easy differentiation among the habitats included in this manual. The decision tree allows readers to overcome the restraints of varying habitat related terminology in deciding which habitat definitions best describe those in their project area. Brief definitions of each habitat are provided at the end of the key.

1. a. Habitat consists of open water and does not include substrate (**Water Column**)
   b. Habitat includes substrate (go to 2)
2. a. Habitat is continually submerged under most conditions (go to 3)
   b. Habitat substrate is exposed to air as a regular part of its hydroperiod (go to 8)
3. a. Habitat is largely unvegetated (go to 4)
   b. Habitat is dominated by vegetation (go to 7)
4. a. Substrate is composed primarily of soft materials, such as mud, silt, sand, or clay (**Soft Bottom**)
   b. Substrate is composed primarily of hard materials, either of biological or geological origin (go to 5)
5. a. Substrate is composed of geologic material, such as boulders, bedrock outcrops, gravel, or cobble (**Rock Bottom**)
   b. Substrate is biological in origin (go to 6)
6. a. Substrate was built primarily by oysters, such as *Crassostrea virginica* (**Oyster Reefs**)
   b. Substrate was built primarily by corals (**Coral Reefs**)
7. a. Habitat is dominated by macroalgae (**Kelp and Other Macroalgae**)
   b. Habitat is dominated by rooted vascular plants (**Submerged Aquatic Vegetation - SAV**)
8. a. Habitat is not predominantly vegetated (go to 9)
   b. Habitat is dominated by vegetation (go to 10)
9. a. Substrate is hard, made up materials such as bedrock outcrops, boulders, and cobble (**Rocky Shoreline**)
   b. Substrate is soft, made up of materials such as sand or mud (**Soft Shoreline**)
10. a. Habitat is dominated by herbaceous, emergent, vascular plants. The water table is at or near the soil surface or the area is shallowly flooded (**Marshes**)
    b. Habitat is dominated by woody plants (go to 11)
11. a. The dominant woody plants present are mangroves, including the genera *Avicennia*, *Rhizophora*, and *Laguncularia* (**Mangrove Swamps**)
    b. The dominant woody plants are other than mangroves (go to 12)
12. a. Forested habitat experiencing prolonged flooding, such as in areas along lakes, rivers, and in large coastal wetland complexes. Typical dominant vegetation includes bald cypress (*Taxodium distichum*), black gum (*Nyssa sylvatica*), and water tupelo (*Nyssa aquatica*). (**Deepwater Swamps**)
    b. Forested habitat along streams and in floodplains that do not experience prolonged flooding (**Riverine Forests**)

Water column - A conceptual volume of water extending from the water surface down to, but not including the substrate. It is found in marine, estuarine, river, and lacustrine systems.

Rock bottom - Includes all wetlands and deepwater habitats with substrates having an aerial cover of stones, boulders, or bedrock 75% or greater and vegetative cover of less than 30% (Cowardin et al. 1979). Water regimes are restricted to subtidal, permanently flooded, intermittently exposed, and semi-permanently flooded. The rock bottom habitats addressed in *Volume Two* include bedrock and rubble.

Coral reefs - Highly diverse ecosystems, found in warm, clear, shallow waters of tropical oceans worldwide. They are composed of marine polyps that secrete a hard calcium carbonate skeleton, which serves as a base or substrate for the colony.

Oyster reefs - Dense, highly structured communities of individual oysters growing on the shells of dead oysters.

Soft bottom - Loose, unconsolidated substrate characterized by fine to coarse-grained sediment.

Kelp and other macroalgae - Relatively shallow (less than 50 m deep) subtidal and intertidal algal communities dominated by very large brown algae. Kelp and other macroalgae grow on hard or consolidated substrates forming extensive three-dimensional structures that support numerous plant and animal communities.

Rocky shoreline - Extensive littoral habitats on high-energy coasts (i.e., subject to erosion from waves) characterized by bedrock, stones, or boulders with a cover of 75% or more and less than 30% cover of vegetation. The substrate is, however, stable enough to permit the attachment and growth of sessile or sedentary invertebrates and attached algae or lichens.

Soft shoreline - Unconsolidated shore includes all habitats having three characteristics: (1) unconsolidated substrates with less than 75% aerial cover of stones, boulders, or bedrock; (2) less than 30% aerial cover of vegetation other than pioneering plants; and (3) any of the following water regimes: irregularly exposed, regularly flooded, irregularly flooded, seasonally flooded, temporarily flooded, intermittently flooded, saturated, or artificially flooded (Cowardin et al. 1979). This definition includes cobble-gravel, sand, and mud. However, for the purpose of this document, cobble-gravel is not addressed.

Submerged aquatic vegetation (SAV; includes marine, brackish, and freshwater) - Seagrasses and other rooted aquatic plants growing on soft sediments in sheltered shallow waters of estuaries, bays, lagoons, rivers, and lakes. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Marshes (marine, brackish, and freshwater) - Transitional habitats between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water tidally or seasonally. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Mangrove swamps - Swamps dominated by shrubs (*Avicenna, Rhizophora*, and *Laguncularia*) that live between the sea and the land in areas that are inundated by tides. Mangroves thrive along protected shores with fine-grained sediments where the mean temperature during the coldest month is greater than 20º C; this limits their northern distribution.

Deepwater swamps - Forested wetlands that develop along edges of lakes, alluvial river swamps, in slow-flowing strands, and in large coastal-wetland complexes. They can be found along the Atlantic and Gulf Coasts and throughout the Mississippi River valley.

They are distinguished from other forested habitats by the tolerance of the dominant vegetation to prolonged flooding.

Riverine forests - Forests found along sluggish streams, drainage depressions, and in large alluvial floodplains. Although associated with deepwater swamps in the southeastern United States, riverine forests are found throughout the United States in areas that do not have prolonged flooding.

THE HUMAN DIMENSIONS CHAPTER

The discussion of human dimensions helps restoration practitioners better understand how to select measurable objectives that allow for the appropriate assessment of the benefits of coastal restoration projects to human communities and economies. Traditionally, consideration of human dimensions issues has not been included as a standard component of most coastal restoration projects. Most restoration programs do not currently integrate social or economic factors into restoration monitoring, and few restoration projects have implemented full-scale human dimensions monitoring. Although some restoration plans are developed in an institutional setting that require more deliberate consideration of human dimensions impacts and goals, this does not generally extend to the monitoring stage. It is becoming increasingly evident, however, that decisions regarding restoration cannot be made solely by using ecological parameters alone but should also involve considerations of impacts on and benefits to human populations, as well. Local communities have a vested interest in coastal restoration and are directly impacted by the outcome of restoration projects in terms of aesthetics, economics, or culture. Human dimensions goals and objectives whether currently available or yet to be developed should reflect societal uses and values of the resource to be restored. Establishing these types of parameters will increase the public's understanding of the potential benefits of a restoration project and will increase public support for restoration activities.

While ecologists work to monitor the restoration of biological, physical, and chemical functional characteristics of coastal ecosystems, human dimensions professionals identify and describe how people value, utilize, and benefit from the restoration of coastal habitats. The monitoring and observation of coastal resource stakeholders allows us to determine who cares about coastal restoration, why coastal restoration is important to them, and how coastal restoration changes people's lives. The human dimensions chapter will help restoration practitioners identify:

1) Human dimensions goals and objectives of a project
2) Measurable parameters that can be monitored to determine if those goals are being met, and
3) Social science research methods, techniques, and data sources available for monitoring these parameters

This chapter includes a discussion of the diverse and dynamic social values that people place on natural resources, and the role these values play in natural resource policy and management. Additionally, some of the general factors to consider in the selection and monitoring of human dimensions goals/objectives of coastal restoration are presented, followed by a discussion of some specific human dimensions goals, objectives, and measurable parameters that may be included in a coastal restoration project. An annotated bibliography of key references and a matrix of human dimensions goals and measurable parameters are provided as appendices at the end of this chapter. Also included, as an appendix, is a list of human dimensions research experts (and their areas of expertise) that you may contact for additional information or advice.

The final four chapters of this manual are designed to provide readers with additional information that should enhance their ability to develop and carry out strong restoration monitoring plans. Chapter 15 reviews methods available for choosing areas or conditions to which a restoration site may be compared both for the purpose of setting goals during project planning and for monitoring the development of the restored site over time. Chapter 16 is a listing of generalized costs of personnel, labor, and equipment to assist in the development of planning preliminary cost estimates of restoration monitoring activities. Some of this information will also be pertinent to estimating costs of implementing a restoration project as well. Chapter 17 provides a brief description of the online review of monitoring programs in the United States. The database can be accessed though the NOAA Restoration Portal (http://restoration.noaa.gov/). This database will allow interested parties to search by parameters and methodologies used in monitoring, find and contact responsible persons, and provide examples that could serve as models for establishment or improvement of their own monitoring efforts. Chapter 18 is a summary of the major United States Acts that support restoration monitoring. This information will provide material important in the development of a monitoring plan. A Glossary of many scientific terms is also provided at the end of the document.

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CHAPTER 5: RESTORATION MONITORING OF KELP AND OTHER MACROALGAE

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INTRODUCTION

Marine macroalgae are multicellular photosynthetic organisms (kingdom: Protista) that are generally located in shallow subtidal (usually less than 50 meters water depth) and low intertidal zones of the oceans. They are found attached to hard substrates (Foster and Schiel 1992) and consolidated sediments (hardened sand). Macroalgae range from a few millimeters to several tens of meters in size. Their presence builds a three-dimensional habitat that often supports numerous animal assemblages. There are three categories of macroalgae:

Red (Phylum Rhodophyta)
Green (Phylum Chlorophyta), and
Brown (Phylum Phaeophyta)

Macroalgae are categorized according to different pigments that they use to convert sunlight into energy through photosynthesis. Although the different groups often display the color for which they are named, this can be misleading. All algal types contain at least one type of the green pigment chlorophyll. In addition, red algae contain red and blue pigments called phycobilins, some of which absorb blue light. Since blue light penetrates water to a greater depth than light with longer wavelengths, these pigments allow red algae to photosynthesize and live at greater depths (Woelkerling 1990; Druehl 2000). Green algae contain two types of chlorophyll pigments that give them their green color and allow them to photosynthesize and absorb red light (Druehl 2000). Most green algae are restricted to shallow waters because the red light that they can absorb does not penetrate deep into the water column. Brown algae contain the brown pigment fucoxanthin that reflects yellow light as well as orange pigments called carotenoids (Druehl 2000).

Within the brown algae category, kelp (order: Laminariales) and other species of the orders Dictyotales, Desmarestiales, and Fucales are particularly important as habitat builders and indicator species. Kelp plants in particular can be extremely large and have astonishing growth rates with up to 50 centimeters per day (Wheeler and Druehl 1986). Kelp can be annual (live only one summer) or perennial (live for several years). Some of the largest kelp species (e.g., *Nereocystis luetkeana*) are annual species that reach their full size within only one summer. Kelp is restricted to cold temperatures, occuring in the middle latitudes of both the northern and southern hemispheres - off the West coast of North America from Alaska to Baja California, the Northeast coast of North America, and off the coasts of South America, South Africa, and Southern Australia (Figure 1).

Only benthic brown marine macroalgae (phylum: Phaeophyta, class: Phaeophyceae), particularly kelp species, are discussed in this chapter because most restoration work pertaining to macroalgae is performed in kelp communities. Kelp plant species discussed in this chapter are those found along the West and Northeast coasts of the United States that have potential for successful laboratory culture, transplanting, and reforestation.

Kelp forests are among the most complex, diverse, and productive marine habitats found on the planet. They vary in size from a few to

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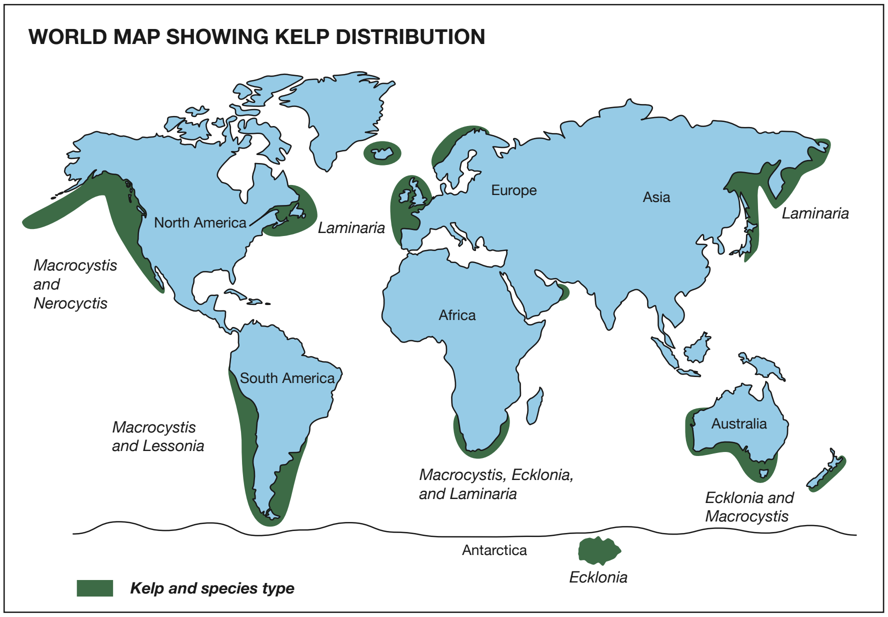

Figure 1. Worldwide distribution of kelp forests. Map courtesy of Raffaelli and Hawkins, (1996), Intertidal Ecology, Chapman and Hall, London, 356 pp.

many plants, and from several square meters to several thousand square kilometers in size. Kelp habitats are often comprised of multiple vegetation layers. The canopy is formed by extremely large kelp species, reaching up to 30 meters from the bottom to the water surface. These canopy-forming species possess gas-filled floating structures which raise the algae to the surface. The understory kelp species form a bed that only reaches several meters above the bottom. Beneath the understory, many other algal species build a turf layer. These layers support hundreds of species of fishes and thousands of invertebrate species.

The dominant kelp species along the U.S. coasts belong to the genera *Macrocystis* (giant kelp) (Figure 2), *Nereocystis* (bull kelp), and *Laminaria* (forest kelp). In areas along the temperate U.S. West coast, *Macrocystis pyrifera* and *Nereocystis luetkeana* are the dominating canopy-forming kelp species, while *N. luetkeana* and *Alaria fistulosa* (winged kelp) dominate in Alaska (Druehl 1978). The extensive kelp forests in Southern California are dominated by the single canopy-forming species, *Macrocystis pyrifera*, which ranges from the low intertidal zone to more than 60 meters deep and found from Sitka, Alaska to San Hipolito Point, Baja California (Abbott and Hollenberg 1976; North 1971). A dense understory can be created by smaller kelp such as *Laminaria*, *Agarum*, *Eisenia,* and *Pterygophora*. Along the U.S. North Atlantic coast, kelp forests are formed by smaller non-canopy species with dominant species being *Laminaria* spp., *Alaria* spp. (winged kelp), and *Agarum* spp. (colander weed). These kelp forests grow from the subtidal fringe to depths of 50 meters and are found from Long Island Sound to beyond Newfoundland.

Figure 2. Giant kelp (*Macrocystis pyrifera)* showing fronds. Photo courtesy of Russell Bellmer, United States Fish and Wildlife Service.

Alaria spp. tend to occupy the low intertidal range, *Laminaria* spp. are often found in the intermediate depths, and *Agarum* spp. occupy the deeper areas. These species and other species of kelp forest understory exhibits inconsistent zonation. Complex interactions driving the structure and zonation of kelp beds include competition for light. *Alaria esculenta* (dabberlocks) for example, grows where *Laminaria* spp. do not overshadow it. Shading by large kelp may also prevent the growth of small juveniles. The abrasive whiplash effect of large kelp blades created by water movement can also prevent the establishment of new kelp recruits. New kelp recruits establish during late winter and early spring when the kelp forests are less dense because the annual species die back. During that time, light penetrates to the bottom.

Growth of kelp is triggered by the interaction of light and nutrient availability, both of which are needed to support the high growth rates in kelp. While light is abundant in summer, nutrients are often depleted due to thermal stratification and phytoplankton production. In contrast, nutrients usually accumulate during the winter. This results in late winter and early spring as the main growing season for kelp because both light and nutrients are available. Plant growth can become nutrient limited in summer and fall, except where nutrients are continually replenished by tidal mixing. In Southern California Bight, nutrient levels are low in the summer and fall, especially above the thermocline, resulting in reduced *Macrocystis* growth and deterioration of the giant kelp canopies.

Kelp and other macroalgal communities play important ecological and economic roles. Ecologically, they provide shelter, breeding, feeding, and nursery grounds as well as recruitment areas for various marine organisms such as adult and juvenile fish and economically important crustaceans (e.g., lobsters and crabs). Kelp forests also help to reduce wave energy and currents, allowing sediment to settle to the bottom and improving water quality and clarity. These habitats are particularly important as a food source for many grazers including gastropods and sea urchins, and even deteriorating kelp provides detritus for numerous detritivores. Sea urchins (e.g., *Strongylocentrotus* spp.) (Figure 3) are common kelp grazers, and, in areas where urchin abundance is not controlled by predation, large urchin populations can completely eliminate kelp forests (Estes and Duggins 1995). These de-forested areas are called urchin barrens.

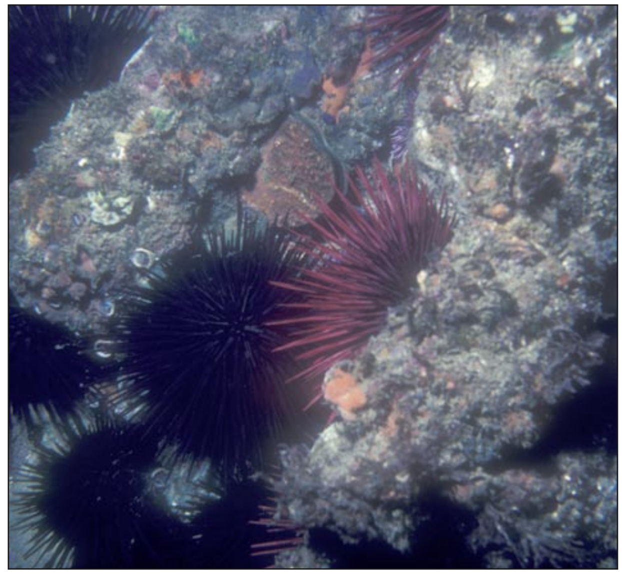

Figure 3. Sea urchins sit attached to rocky substrates. Photo courtesy of Russell Bellmer, United States Fish and Wildlife Service.

In Maine, sea urchin harvesting is an important industry with over 12,000 metric tons landed in 1992 (Johnson and Mann 1993). Sustainable harvesting may help to protect kelp forests from overgrazing. Another natural threat to kelp populations is the explosive populations of encrusting bryozoans (*Membranipora* spp.) which can completely cover the blades, thereby blocking sunlight, physically damaging the blade and stipes, reducing flexibility, and increasing breakage.

Economically, macroalgae are harvested and used to produce alginate, which serves as an emulsifying and binding agent in food and pharmaceutical products (Frey 1971). Kelp species are also an important part of traditional food in many regions of the world, including Asia, South America, and Alaska. Kelp communities also support various recreational activities such as fishing and scuba diving. The use of kelp in commercial products as well as their value in recreational uses contribute largely to the worldwide economy. For instance, the kelp harvest in California was valued at $4 million in 1991 and $3 million in 1992, and the State of California received a percentage of the dollars earned from kelp harvesting.

HUMAN IMPACTS TO KELP AND OTHER MACROALGAE

Over the years, kelp and other macroalgae populations have declined due to natural occurrences and human impacts. Some human activities responsible for this decline include:

- Industrial and sewage discharges
- Oil spills
- Boating, fishing, and diving activities
- Coastal development
- Harvesting, and
- Removal of species

These activities can be placed in three categories of impacts: coastal pollution, physical damage, and removal of species.

Coastal Pollution

Coastal pollution from agricultural, municipal, and industrial sources can impact macroalgal communities. Eutrophication in coastal waters may result in the excessive growth of epiphytes and epifauna on the blades, causing the plants to sink to the bottom or break and die (Dayton 1985). High nutrient levels also increase phytoplankton growth, which results in reduced light penetration and an accompanying reduction in kelp photosynthesis. The turbidity resulting from eutrophication and increased sediment loading may cause burial of kelp and other macroalgae affecting plant growth. Waste materials have the ability to restrict growth and reduce fertility of kelp during its microscopic stages. In addition, sea otter (*Enhydra lutris*) populations may decrease due to poor water quality.

Oil spills also affect kelp communities. Even though oil may not persist following a spill, recovery time for the damaged habitat can be years or even decades. The swimming oil carpet can cover the intertidal range and coat intertidal kelp (e.g., *Alaria* spp.) and other habitat-building algae, such as the ecologically important rockweed (e.g., *Fucus* spp.). Following the *Exxon Valdez* spill in Prince William Sound, Alaska, rockweed did not fully recover until several years after the spill (Stekoll and Deysher 1996). Oil that stays on the surface of the water can cover blades of the kelp canopy, preventing sunlight from reaching the plants. As a result, kelp growth is limited because photosynthesis is reduced or in some cases eliminated. Studies have also shown that the microscopic life stages (gametophytes) of *Macrocystis* spp. are particularly sensitive to oil contamination (Reed et al. 1994). In some cases, cleanup activities following oil spills, such as pressure cleaning, directly affect kelps. The cleanup following the *Exxon Valdez* oil spill devastated some kelp communities and intertidal macroalgae by inhibiting re-sprouts of the holdfast and lowering recruitment rates (De Vogelaere and Foster 1994).

Associated animal communities are also affected by oil spills. Sea otters have thick fur coats that make them particularly susceptible to oil spills. Otters solely rely on their fur for insulation because they lack a blubber fat layer. Oil on otter fur reduces their insulation capacity which can cause otters to experience hypothermia, or even drown if oil coats the air sacks in the fur (Williams et al. 1988). In Alaska, sea urchin populations increased following the decline of the sea otters population due to the *Exxon Valdez* oil spill (Dean et al. 1996). Oil introduced into the intertidal zone will also affect the invertebrate community associated with macroalgae attached to the rocky habitat. Kelp holdfasts in low-energy environments can retain oil for years after a spill, then be weakened until the holdfast-associated animal community is destroyed. For example, a small spill of diesel oil at Macquarie Island in the sub-Antarctic resulted in contamination of kelp holdfasts for at least five years and inhibited the full recovery of the kelp-associated invertebrate community (Smith and Simpson 1998). Similarly, fish communities associated with kelp forests show delayed recovery due to oil spills.

Physical Damage

Construction and logging activities related to coastal development often affect kelp forests directly, resulting in increased sediment loads into coastal waters. The sediments decrease light penetration and thus, photosynthesis and growth of algae, especially the overwintering microscopic life stages of kelp which are susceptible to smothering and abrasion by sediments.

Other human activities that can directly impact kelp communities by uprooting plants and physically damaging kelp forests include:

- Dragging of heavy bottom gear (e.g., groundfish trawls and scallop dredges)
- Hook and line fishing
- Use of crab and lobster pots
- Setting and removing of gill nets
- Boat traffic
- Commercial harvesting by divers, and
- Intense recreational free diving and scuba activities

The exact nature and magnitude of these impacts and the rate of recovery have not been adequately studied. However, observations by scientists in California noted areas as large as several square meters void of kelp because of such activities.

One human activity that directly affects kelp communities is the harvesting of kelp plants. These plants are harvested in both Maine and California and used commercially as fertilizer, animal feed, and packing materials to ship commercial species such as lobsters, marine bait worms, and crabs (White 1993). Kelp plants are also harvested to extract alginic acid (alginate), a colloidal product used for thickening, suspending, stabilizing, emulsifying, and film-forming (McPeak et al. 1988). Approximately half of the alginate produced is used to make ice cream and other dairy products; the remainder is used in products such as shaving cream, toothpaste, rubber, and paint (McPeak et al. 1988). While much research has gone into trying to develop a sustainable commercial kelp harvest in Southern California, there is an increasing potential for this resource to be greatly depleted due to the cumulative impacts of harvesting, chronic oil and chemical spills, industrial and urban runoff, sewage outfalls, and physical plant damage caused by boats and scuba divers. In addition, the fish and invertebrate community associated with the surface layer of the canopy, which is removed in the harvest, becomes impoverished.

Kelp is also harvested extensively in the Gulf of Maine. In the 1940s, up to 3,000 tons of kelp were harvested each year in southwestern Nova Scotia, largely as a source of alginate (Sharp and Carter 1986). Surveys of the same area in the 1980s indicated that the yearly plant production levels had significantly increased and represented “a significant opportunity for exploitation” (Sharp and Carter 1986). There is, however, limited scientific information about the biological effects of kelp harvest on the plants themselves or the associated communities. One effect of the continual removal of kelp in a given area is that light would be able to penetrate deeper into the water column and promote microalgal and macroalgal growth, potentially outcompeting new kelp plant recruitment (Pearse and Hines 1979; Reed and Foster 1984).

Removal of Animal Species

Unlike the other impacts that often directly affect kelp and other macroalgae, ecosystem changes, such as human removal of an animal species that controls the population of another species, can indirectly affect kelp communities. This situation was seen in the North Pacific where the removal of top predators had cascading effects on the trophic structure, allowing kelp grazers to thrive and eliminate kelp forests. It is suggested that industrial whaling during the late 1800s reduced great whale populations in the North Pacific Ocean. Killer whales (*Orcinus orca*), the primary predator of great whales (after humans), were forced to switch prey, first to seals (e.g., *Halichoerus grypus, Phoca vitulina*) and sea lions (e.g., *Eumetopias jubatus, Callorhinus ursinus*), then to smaller prey such as sea otters (*Enhydra lutris*) (Estes et al. 1998; Springer et al. 2003). This has affected sea otter populations to the same or greater extent as the impact from hunting for sea otter pelts in the late 1700s and early 1800s. The sea otter population in the Aleutian Islands is about 10 to 20 percent of their historical levels, causing the sea urchin populations in these areas to explode (Estes and Duggins 1995). Sea urchins have removed much of the kelp forests, resulting in loss of species diversity and nearshore productivity. Sea otter populations along the California coast have been declining recently, possibly due to a combination of infectious diseases, parasites, and pollution.

Biological communities that are integrally dependent on physical structures formed by living organisms (e.g., kelp forests, coral reefs) are inherently slow to recover from severe impacts such as the ones discussed above. In some cases where the structure-forming species (e.g., kelp) actually stabilize the habitat, permanent habitat modification can result from an acute incident that destroys the key structuring species. Kelp recovery from impacts may depend on:

- The actual impacts from commercial and recreational activities
- Toxicological and biological damage associated with incidents (e.g., oil spills)
- Damage incurred during cleanup operations
- The persistence of contamination
- Timing of incidents and time between incidents
- Impacts on predators of kelp grazers, and
- The inherent ability of the community to recover

These examples of functional inter-relationships highlight the complexity of kelp and other macroalgal ecosystems, as well as the need to monitor restoration activities and their benefits to adjacent ecosystems.

RESTORATION EFFORTS

The essential aspect of planning and implementing restoration efforts is the proper identification of the problems affecting kelp habitats. The causes for deterioration of kelp habitat can differ among areas and regions. Once the causes (e.g., grazer impacts, human disturbances) are identified, appropriate restoration strategies can be developed. Larger ecosystem consequences of restoration activities should also be considered during the planning process.

Various researchers, agencies, and organizations, such as the Scripps Institution of Oceanography, Kelco Company, California Department of Fish and Game, and National Oceanic and Atmospheric

Administration (NOAA), have restored kelp habitats in the United States. These activities are aimed to increase kelp forest acreage and maintain habitat functions in support of coastal ecosystems which provide biodiversity, biomass, and economic opportunities. In the early 1960s, the Scripps Institution of Oceanography and Kelco Company began a cooperative program to develop techniques to protect and restore kelp forests off Southern California in order to keep the harvest industry viable. These efforts focused on predation control (i.e., sea urchin removal). Between 1967 and 1980, kelp restoration was then conducted along the Palos Verdes Peninsula in California by the Institute of Marine Resources and California Department of Fish and Game. This work combined sea urchin control and kelp transplanting with structural monitoring.

By the early 1990s, the California Department of Fish and Game's Artificial Reef Program and the Southern California Edison Company built artificial reefs in Mission Bay within San Diego County and San Clemente that supported the growth of kelp plants. Such reef-building efforts proved that if limited substrate is a factor in kelp forest restoration, then creating new reef substrate could increase the capacity for kelp forest expansion.

Recently, the NOAA Restoration Center funded the California Coastkeeper Alliance to develop facilities, training, and transplanting implementation methods for kelp forest development along the Southern California coast. These activities include the culture of kelp plants from field plants and attaching the holdfasts to natural and artificial reefs in Southern California. Recent research has studied the use of artificial kelp plants to reduce grazer impact in Southern California. Artificial (plastic) kelp plants are site-specifically designed and located on the perimeter of the transplant area to sweep the substrate and create a whiplash effect, moving the sea urchins away from the transplanted kelp (Vasquez and McPeak, 1998). While these efforts have had some success to date, there is a need for long-term monitoring as well as development of new restoration techniques.

Restoration practitioners can learn more about specific kelp and macroalgae restoration activities through NOAA's Restoration Center database of restoration projects. This web-based database can help in planning a restoration project, contacting restoration practitioners, and sharing information. The restoration project database can be found at: http://restoration.nos.noaa.gov/htmls/rpi_query/rpi_query.html. California kelp restoration activities may be found at: http://www.dfg.ca.gov/habitats. Bedford (2001) presents an excellent overview of the kelp forest restoration activities in California. More information from NOAA on laboratory procedures is available at: http//www.seagrant.noaa.gov/index.html and http//www.nmfs.noaa.gov/aquaculture.htm. Information on culturing macroalgae may also be obtained at: http://www.seacare.org.au/html/articles.htm.

Monitoring Kelp and Other Macroalgae

Most emphasis in macroalgal habitat restoration has been placed on kelp forests and intertidal rockweed (e.g., *Fucus* spp.) habitats. Kelp restoration projects are designed to accelerate the regeneration of existing or historical kelp forests, stabilize the community to support new plant recruitment, and remove or reduce human-induced disturbances. After identifying the need for a potential restoration effort, a detailed restoration plan must be developed. This plan has to address the specific impacts in the region, goals and objectives of the restoration project, and the conceptual model to measure progress toward meeting those goals and objectives. Consideration must be given to site selection, methods to be used, proper care and handling of samples, the benefits of cultured algae, chemical and physical conditions of the habitat, and any short- and long-term maintenance requirements. In addition, coordination and collaboration needs, regulatory requirements, parameters to be monitored to track progress, and monitoring time frame must be established. Monitoring should be performed before, during, and after the restoration effort to measure progress and success. Modifications may have to be made in design, implementation, and techniques to help ensure the potential for the project to obtain the pre-defined goals and objectives. This is referred to as adaptive management.

Parameters frequently monitored in kelp and other macroalgal habitats include (Foster and Schiel 1992):

- Abundance and growth rates of kelp and macroalgae
- Species composition
- Plant characteristics (e.g., length, holdfast size, stem density, plant density, rate of canopy closure, and aerial extent)
- Kelp recruitment
- Presence and abundance of kelp-associated species with known key effects on habitat health (e.g., otters, sea urchins, other grazers)
- Diversity of the habitat
- Tides and hydrographical conditions
- Temperature
- Sediment texture
- Salinity, and
- Water quality

Parameters monitored should be specific to the proposed restoration plan and design goals, and may vary depending on the project location and ecological situation. Where practicable, plans should consider transfer metrics to relate an individual project to others in order to increase the knowledge base of restoration techniques.

Species selection for monitoring is most important in assessing whether the kelp restoration project is appropriate to improve the structural and functional characteristics of the kelp forest. Ecologically important kelp and other algal species, invertebrates, and vertebrates need to be selected for monitoring. The primary objective in selecting taxa for monitoring is to provide a representative cross-section of structural and functional elements so that these taxa may serve as indicators of system status.

If the primary goal is to restore the faunal community, general criteria to select species include consideration of:

- Specific legal mandate(s) (e.g., protection of certain species)
- Species targeted by commercial or recreational harvest
- Exceptionally common species or characteristic of entire communities
- Species with known impacts on kelp (e.g., grazers, non-native invasive species)
- Species endemic to the study area, and
- Species with an extremely limited distribution

The selected species should prey on a variety of food types, including detritivores, primary producers, obligate herbivores, and higher level predators. In addition, the species should span mobility ranges from sessile filter feeders and sedentary grazers to highly mobile planktivorous fishes and wide ranging benthic foragers. Reproductive strategies of these species should be diverse, from live births as seen in surfperches (e.g., *Hyperprosopon argenteum*) to precarious release of gametes into the sea by many invertebrates (e.g., abalone and sea urchins) to those with long-lived pelagic larvae (e.g., the spiny lobster, *Panulirus interruptus)*. The selection of species should provide opportunities to detect ecosystem benefits and many facets of human impacts, from pollution to habitat disturbance and direct removal.

Standardization of monitoring methods and locations should be considered. Standardized techniques, while not optimum for a particular site or study, often provide a higher level of scientific value as part of a regional database or comparable temporal series. Monitoring stations should consider prevailing winds, water currents, bathymetry of adjacent areas, and terrestrial inputs, as these all greatly influence marine communities. Upwelling nutrients from deep basins produce exceptionally productive food webs and different temperature regimes than those present at the shallow sides of islands, headlands, or mainlands. Standardized protocols can also facilitate long-term monitoring of transition areas from one marine province to another (e.g., Californian to Oregonian provinces) which are especially susceptible to impacts with changing environmental conditions.

Selecting adequate monitoring techniques for the specific metrics of a restoration project are critical to obtaining useful data. The array of organisms and physical settings associated with kelp forests and macroalgal environments require equally diverse monitoring approaches to assess their population dynamics. Accuracy (i.e., the closeness of a measured value to its true value) is an important attribute of a monitoring technique, but precision (i.e., the closeness of repeated measurements of the same entity) and the ability to sample several target species at once are also required for the efficient sampling of an underwater habitat. Accuracy and precision of monitoring techniques used in long-term assessment programs must also be maintained by many generations of field samplers. Considerable biological and technical training - including biota identification, laboratory and field biological techniques, advanced technical scuba, boat handling, and self-rescue - must be provided for all personnel engaged in restoration monitoring activities. Finally, the selected monitoring techniques must provide values that do not vary among observers. The techniques must not significantly reduce populations of organisms being monitored, alter their environment, or introduce non-native species. Current technology for remote sensing or monitoring of kelp forest organisms from the sea surface is neither accurate nor precise enough to record population dynamics of key species. Development of diving equipment has generated various monitoring techniques that have potential for providing accurate and precise measures of population abundance, distribution, age structure, reproduction, recruitment, growth rate, mortality rate, sex composition, and phenology[4] of kelp forest organisms, but the measurements must be taken in close proximity to the organisms.

In summary, the selection of monitoring techniques for restoration should be evaluated using their ability to meet the following criteria:

- Accurately assess the structure and/or functional characteristics of canopy, understory, benthos, and water column,
- Sample targeted ecosystem-significant algae, fish, and invertebrate species accurately and precisely
- Identify potential impacts (e.g., pollution, disease, predation, competition, introduction of non-native invasive species) to target species and other biota
- Ensure efficiency, effectiveness, and repeatability of all monitoring methods and stations (e.g., by using global positioning systems (GPS), mapping coordinates)
- Create accurate permanent records for quality assurances and control and future analyses
- Address requirements and training necessary for observers, complexity of monitoring methods, and need for specialized equipment

[4] The study of plant growth and development related to the timing of different growth stages.

- Establish permanent stations and transects to give appropriate level of precision
- Develop a conceptual model of the questions to be answered by each monitoring technique
- Monitor all aspects of culturing techniques with accuracy and precision, and
- Develop and implement a plan for estimating risks of the potential for the introduction of non-indigenous marine organisms and methods to minimize these potential risks

STRUCTURAL CHARACTERISTICS OF KELP AND OTHER MACROALGAE

The primary structural components of kelp and other macroalgae relevant to restoration monitoring include biological, physical, hydrological, and chemical characteristics. The identified structural characteristics will help restoration practitioners determine whether kelp and/or other macroalgae can survive and grow in a potential restoration area and whether the habitat is functioning efficiently following restoration efforts. With the proper set of structural parameters in place, functional parameters (discussed in next section) may be more easily identified to create a sound science-based monitoring program. Two matrices at the end of this chapter (also found in *Volume One* for all habitats) show the connection between the habitat's structural and functional characteristics and the parameters that should be considered for monitoring.

The major structural characteristics, factors influencing them, and methods to monitor them are discussed in this section. Project goals, costs, and types of data to be collected must be considered when selecting these parameters. Experts in the field should also be consulted to determine the best method for a specific area.

The basic structural components of kelp forests include:

Biological

- Habitat created by plants (i.e., kelp and other macroalgae)

Physical

- Sediment (grain size and sedimentation)
- Light availability
- Turbidity
- Water temperature

Hydrological

- Current velocity and tides
- Wave energy and protection
- Water sources (i.e., nutrients and water quality)

Chemical

- Salinity

These characteristics dictate where kelp forests can grow and how well they perform certain functions (e.g., providing fish and invertebrate habitat, improving water quality) and therefore, should be among the first things measured during a monitoring effort. The hydrology and geomorphology of a potential restoration area are not characteristics that will be monitored for change over time but should be established for the basic understanding of a selected site. In kelp and macroalgal restoration projects requiring rock or sediment placement, however, practitioners will need to monitor substrate placement, stability, elevations, and topographic diversity for a period before transplant attachment to determine if the planned substrate conditions have been achieved.

BIOLOGICAL

Habitat Created by Plants (i.e., kelp and other macroalgae)

Among macroalgae, kelp species obtain the largest size and have the highest structural complexity (Figure 4). They are attached to the substrate with a holdfast from which a stipe extends. Continuous growth of a frond occurs from its tip or apical meristem (forming one or more blades).

Kelp holdfasts often have finger-like extensions (haptera) that take advantage of small-scale

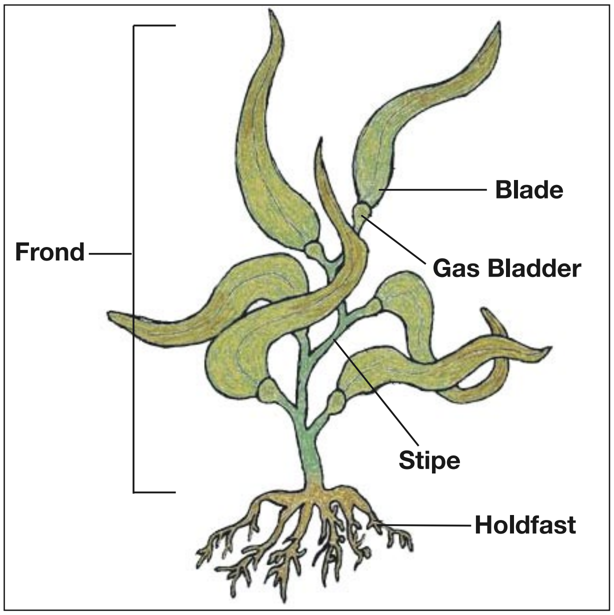

Figure 4. Parts of the kelp plant. Photo courtesy of Andrew Mason, NOAA, Center for Coastal Monitoring and Assessment, Silver Spring, MD.

Figure 5. The stipe of a kelp plant attached to hard bottom. Photo courtesy of Russell Bellmer, United States Fish and Wildlife Service.

structures of the substrate for attachment (Figure 5). They create a microhabitat for many specially adapted organisms such as polychaete worms, brittle stars, and small crustaceans. New haptera are added every year in perennial kelp species.

Stipes can be absent (e.g., stipe-less kelp, *Hedophyllum sessile*) or can extend several meters (e.g., bull kelp, *Nereocystis luetkeana)*. In the latter case, the stipe retains actively growing (meristematic) tissue. The number of stipes arising from a single holdfast varies from one to more than 50. One or more blades arise from the stipes. The blades continue to grow from the meristematic tissue at their basal portion while they deteriorate from the tip. Some kelp blades have a rippled surface which creates turbulent flow of the surrounding water across the blades to increase nutrient uptake. In canopy-forming kelp species, gas-filled floats (pneumatocysts) are located between the stipe and the blade. The pneumatocysts allow the blades to stay near the surface in the sunlight for photosynthesis.

Kelp life history includes the alternation of two generations: a large sporophyte commonly known as the kelp and a small gametophyte consisting of only several cells (Figure 6). In late summer, the sporophyte produces spores in certain sections of the blades (sori) or on specialized blades (sporophylls). These spores are the major dispersal stage in kelps. They undergo meiosis (i.e, the reduction of the DNA to a single set), and then settle and grow into a haploid gametophyte just a few cells in

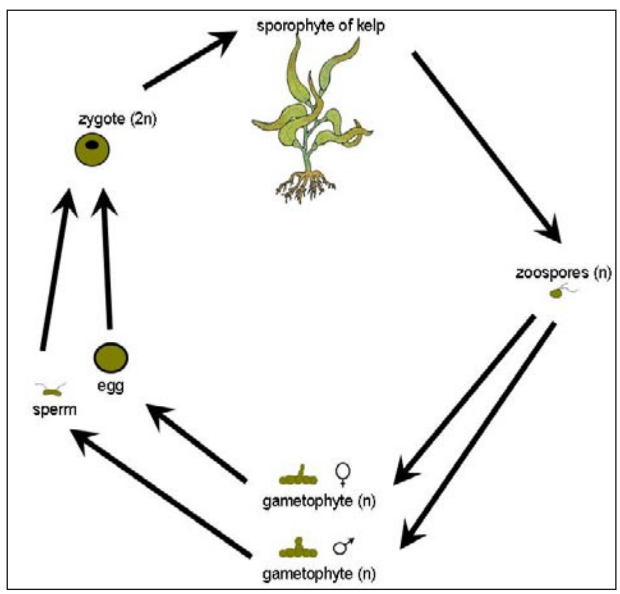

Figure 6. Kelp life cycle. Diagram courtesy of Andrew Mason, NOAA Center for Coastal Monitoring and Assessment.

size. In annual kelp species, the gametophyte is the overwintering stage. Male and female gametophytes then produce sperm and eggs, respectively, which fuse into zygotes from which new diploid sporophytes grow out.

It is important to understand this principle alternation of two physically different generations for the purpose of kelp monitoring and restoration because both generations have different requirements and weaknesses with regard to their physical and biological environment. Potential restoration sites must be screened for environmental requirements pertaining to both sporophytic and gemetophytic life stages if re-establishment is to be successful.

Canopy-forming kelp species, such as *Macrocystis* spp. and *Nereocystis luetkeana,* extend to the surface and thus, effectively block light penetration to the substrate below. This gives a forest-like appearance to scuba divers (as shown in Figure 7) and hence the term kelp forests. Certain animals associated with the kelp forests, especially fishes, are specialized to live among the top floating part of the canopy, while others are specialized to live in the midwater section. The holdfasts host their own specialized community of associated invertebrates. Many benthic invertebrates are also associated with the smaller understory kelp species, which provide efficient shelter and three-dimensional habitat. A diverse community of red algae (e.g., *Gigartina* spp.) also thrives in the smaller understory. The presence and physical structure also influence hydrological properties, such as the slowing of currents. Resulting effects include increased sedimentation and accumulation of finer sediment in the low current areas within the kelp forests. The three-dimensional structure of kelp forests and the influenced physical oceanographic processes are noticeably different than adjacent non-forested areas.

Some of the more common species of kelp include:

Figure 7. Diver observing kelp growth. Photo courtesy of Russell Bellmer, United States Fish and Wildlife Service.

Giant kelp (*Macrocystis* spp.)
Bull kelp (*Nereocystis luetkeana, Pterygophora californica)*
Forest kelp (*Laminaria* spp.)
Winged kelp (*Alaria* spp.)
Colander weed (*Agarum* spp.)
Southern sea palm (*Eisenia arborea)*
Stipe-less kelp (*Hedophyllum sessile*)
Chain bladder kelp (*Cystoseira osmundacea)*
Furbelows (*Saccorhiza polyschides)*
Feather boa kelp (*Egregia menziesii*), and
Strap kelp (*Lessoniopsis littoralis)*

However, there are many more species of kelp and large macroalgae distributed along the U.S. coasts. Another noteworthy macroalgal group that provides important habitat in intertidal regions is rockweeds such as *Fucus* spp. They also provide habitat structure, as well as shelter from predation and desiccation (i.e., loss of water or moisture) in the intertidal zone.

Another structural component of kelp forests of interest to restoration practitioners is the spatial extent, which can range from a few square meters to thousands of square kilometers. Spatial extent is variable on seasonal and interannual scales and needs to be monitored to understand the dynamics influencing a specific kelp habitat. Causes of kelp forest extent changes should be identified before site-selection of restoration and monitoring sites.

Measuring and Monitoring Methods

Various methods can be used to monitor and track the progress of kelp growth throughout a restoration project toward the goal of a self-sustaining kelp habitat. Digital remote sensing combined with geographical information systems (GIS) is an efficient method to collect and analyze data on changes occurring in kelp forest size and location. Spot satellite imagery, which is a remote sensing method, can be used to map large kelp forests (greater than10 hectares) and has been used along the California coast (Deysher 1993). Images from an Airborne Data and Registration (ADAR) system, a multi-spectral video sensor mounted on an airplane (developed by Positive Systems), can provide a spatial resolution of 2.3 meters in four spectral bands to map aerial extent and condition (Deysher 1993).

Geographic information systems (GIS) may also be used to monitor and analyze *Macrocystis pyrifera* canopy cover at both spatial and temporal scales (Bushing 2000). GIS-based gap analyses can be performed repeatedly on the designated area in relation to the regional ecology, disturbance regime, and persistence of giant kelp (*M. pyrifera*). Analysis of these temporal maps can be used to develop a model representing spatial scales of kelp over time. The disturbance regime and prominent physical variables can also be determined. This method is considered a useful tool for evaluating large-scale kelp communities as part of restoration monitoring efforts (Bushing 2000.)

Direct observation - Trained scuba diving marine biologists provide the most complete and reproducible survey method of kelp and other macroalgal communities. This technique is usually performed by repeated observations of a set of metrics on fixed transects over day and night as well as throughout the year. These efforts may be supplemented with remote sensing (e.g., aerial photography, space mounted sensors), video, and still photography. Surveys are performed to collect sound scientific data on the habitat structure of kelp and other macroalgae, such as:

- Abundance and distribution of individual plants
- Diversity of kelp species
- Reproductive state
- Plant recruitment
- Growth rates
- Canopy closure
- Size of plants
- Animal-induced changes to kelp and other macroalgae and/or substrate, and
- Changes in top predators, especially sea otters

Quadrats - Sample areas that are fixed or randomly placed along transects and commonly used to collect quantifiable data are called quadrats (Figure 8). Quantitative information can include percent cover of the understory kelp species in the quadrat compared to open substrate, red algae and sessile animal cover, stipe counts of kelp, and counts of kelp recruitment on the level of juvenile sporophytes. Canopy-forming kelp is often distributed in patches and cannot be estimated reliably from quadrat counts. For these, a swath of defined width along each side of the transect is counted for canopy kelp. When kelp size is measured, attention should be paid to growth patterns of kelp species which can include growth in length and width. If the kelp forest extends over a significant depth range, each sampling procedure must be performed at multiple depth intervals to account for this factor.

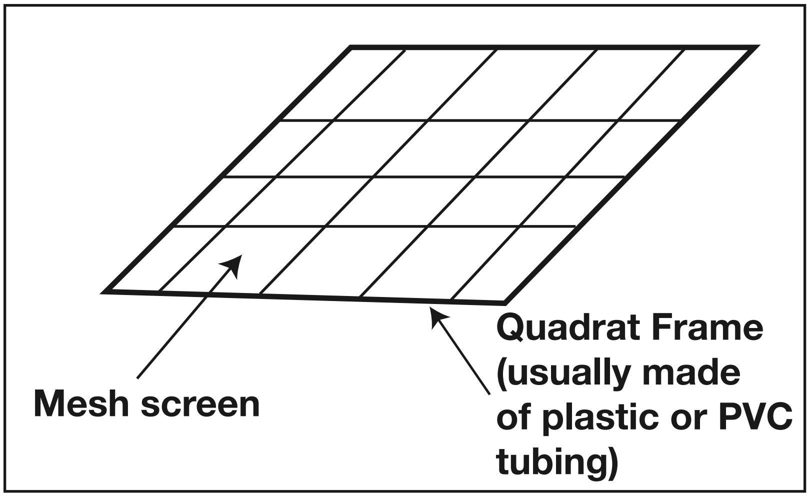

Figure 8. A quadrat, used to make visual assessments within the perimeter of the frame. Diagram courtesy of Felicity Burrows, NOAA National Centers for Coastal and Ocean Science.

Growth markers - Kelp growth can also be monitored by inserting growth markers into the blades or stipes. A growth marker can be as simple as a hole punched just above the meristematic tissue of a kelp blade. They can also be metal buttons that are inserted just above the meristematic tissue. The distance from the growth marker to the base of blade or holdfast is then measured repeatedly over time. The increase in distance per time frame can be expressed as the growth rate.

Both of these transect surveys can be combined with metrics of the functional characteristics of kelp, such as counts of large mobile animals (e.g., seastars, abalone). Swaths are the most common approach to quantify fish, as swaths can be done at various levels (bottom, midwater, top canopy) and encounter fish species enumerated (discussed further in the "Functional Characteristics of Kelp and Other Macroalgae" section).

PHYSICAL

Sediment

Grain size and sedimentation

The sediment composition in kelp forests ranges from bedrock and boulders to cobbles dispersed in sand (*see Geomorphology box*). Some *Laminaria* species are even able to attach their holdfasts to small pebbles buried in sand. The complex surface, crevices, and three-dimensional structures of areas with hard substrates support a variety of other plant and animal species. Adjacent to these hard substrates are often unconsolidated sediment, which is commonly transported back and forth by wave forces throughout the kelp forests. The kelp plant structure slows water movement, thereby allowing suspended sediment to settle to the bottom. More importantly, sediment movements may also affect kelp by covering the thallus and/or smothering the entire plant (Foster and Schiel 1992). Increased sedimentation rates may also reduce the recruitment rate and survival of gametophytes (Devinny and Volse 1978; Foster and Schiel 1992).

Geomorphology

In the matrix, at the end of this chapter, geomorphology is listed as a physical parameter that at a bare minimum should be assessed during restoration however this is in relation to the geomorphology of rocky substrates that support kelp and other macroalgae. A detail discussion on the geomorphology of rocky substrates is discussed in chapter 6: Restoration Monitoring of Rocky Habitats" of this document.

Sampling and Monitoring Methods

Sediment traps - Sediment that drops out of suspension over time (i.e., sedimentation rate) can be collected in sediment traps. The traps can be fixed for extended periods to determine total sediment input, or more importantly over predetermined shorter intervals to allow differentiation of acute sedimentation rates from long-term or seasonal patterns of sedimentation (Hargrave and Burns 1979; Hawley 1988; Rogers et al. 2001). Sediment traps are mainly constructed of several PVC pipes or jars attached to a steel rod and positioned at varying distances above the substrate. Each jar has a lid to seal it before it is removed from the water. Baffles or cones are placed at the top of the jar to prevent mobile organisms that may consume material in the trap from entering. Samples are then filtered, dried, weighed and analyzed in the lab (Hargrave and Burns 1979; Hawley 1988; Rogers et al. 2001).

Light Availability and Turbidity

Light availability

Kelp depends on sufficient light availability for photosynthesis. Wave action keeps the fronds in constant motion, allowing maximum exposure to sunlight and enhancing uptake of nutrients (Barnes and Hughes 1993). Kelp plants have a minimum light availability necessary to perform net photosynthesis. The energy produced during photosynthesis is stored as the carbohydrate laminarin that can be used for growth if sufficient nutrients are available. A study was performed to view the response of the Arctic kelp *Laminaria solidungula* to ambient light and nutrient levels in extreme conditions, when sufficient light is only available in the summer and nutrients are low (Henley and Dunton 1997). The Arctic kelp produces laminarin during summer but does not grow. When nutrient levels increase in the winter, the stored laminarin is used to fuel growth. Results showed that total annual growth was due mainly to light limitations. The minimum light requirements differ for different kelp species; canopy-forming species often need more light, while understory species are often more low-light adapted.

Recruitment of giant kelp (*Macrocystis pyrifera*) gametophytes and embryonic sporophytes in response to reduced light and nutrient availability has also been investigated (Kinlan et al. 2003). Laboratory cultures were provided with either limited light or nutrients for one month and then exposed to non-limiting conditions for ten days. Results showed that gametophytes failed to recruit to sporophytes. Light or nutrient-limited sporophytes survived but experienced slower growth than controls (Kinlan et al. 2003). These results show that limiting light and nutrient resources can inhibit recruitment of embryonic giant kelp sporophytes.

Photosynthetically active radiation (PAR)

PAR is the range of light wavelengths that is absorbed and used by plants for photosynthesis. In California, the effects of PAR on *Macrocystis pyrifera* in shallow waters were monitored (Graham 1996). At shallow depths and high PAR levels, *M. pyrifera* did not recruit or grow to macroscopic size, but rather survived at greater depths where PAR levels were decreased. This corresponded with natural recruitment and sporophyte distributions. Obviously, high PAR inhibited *M. pyrifera* recruitment to shallow water by destroying the post-settlement stages (gametophytes and embryonic sporophytes), which survived only when shaded.

Turbidity

Turbidity is also an important factor affecting the growth of kelp, as greater turbidity leads to reduced light penetration that in turn, affects photosynthesis. Water quality deterioration related to turbidity from coastal development, municipal and industrial discharges, and non-point source runoff has caused reductions in the spatial extent of kelp.

Sampling and Monitoring Methods

Photosynthetically active radiation (PAR) is measured using a quantum sensor at the water surface, throughout the water column, and at the substrate. There are two types of quantum sensors: flat sensors that measure light projecting downward, and spherical sensors that measure light from multiple directions. A spherical sensor should be used for underwater measurements. Quantum sensors can be used along with data loggers to record measurements of PAR at various locations and intervals over time (discussed further in Chapter 9: "Restoration Monitoring of Submerged Aquatic Vegetation (SAV)").

A common method used to estimate turbidity by the depth of light penetration is the use of a secchi disc (Figure 9) which measures water clarity. It is a standard sized (quartered black and white, weighted) plastic disc that is attached to a line and lowered through the water column from the shore, pier, or boat until the disc is no longer visible. This depth is then recorded as the secchi disc depth. Usually, three measurements from the same point are recorded so that the mean of these recordings can be used to establish the relative limit of visibility or turbidity.

Turbidity can also be measured using electronic light extinction sensors. Typically, the reduction in light transmission over a set distance is measured photoelectrically. Alternately, back-scatter or side-scatter may be measured to provide a separate measurement of light extinction due to particles in suspension.

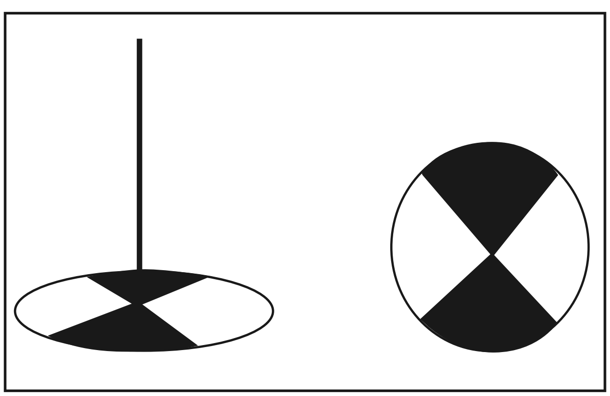

Figure 9. Secchi disc. Diagram courtesy of Felicity Burrows, NOAA National Centers for Coastal and Ocean Science.

A turbidimeter can also measure turbidity in a water sample by passing a beam of light through the water sample and measuring the quantity of light scattered by particulate matter (Rogers et al. 2001).

Water Temperature

Kelp grows best in cooler temperatures below 20ºC and cannot successfully reproduce in warmer temperatures. Increased water temperatures due to terrestrial runoff (including modified river flow regimes), human-induced pressures, and natural events may alter kelp communities. El Niño events are usually accompanied by warmer water temperatures, which reduce kelp growth or even eliminate kelp forests. In California, El Niño disturbances resulted in long-term negative changes in kelp standing stock due to change in the temperature gradient (Tegner et al. 2001). Massive mortality of the intertidal kelp species *Lessonia nigrescens* was seen in northern Chile where very few representatives survived the El Niño event of 1982-83 (Martinez et al. 2003). Recovery after an El Niño event can be very slow, but kelp forests have the ability to completely recover over time. Declines in kelp populations were also noted in relation to warm anomalies after the 1976-1977 regime shift (Wright et al. 2000). Increases in ocean temperatures as a result of global warming may shift the range of kelp populations northward towards currently cooler waters, thereby eliminating them from southern locations where kelp is currently growing at its upper temperature limit.

Sampling and Monitoring Methods

Water temperature can be measured using a thermometer. Scuba divers use thermometers that resemble wrist watches and record temperatures as they descend or ascend through the water column. Various other hand-held commercial instruments can also be used to measure water temperature. A maximum/

minimum thermometer can be left at the study site to record the warmest and coldest water temperatures since the last readings were recorded at the site (Rogers et al. 2001). Small temperature data loggers (developed by HOBO) that record temperature at set intervals for up to several years can also be deployed. Remote thermo-sensors collecting data continuously provide a comprehensive data set that can be used to typify the thermal regime over a long period of time, whereas thermometers used by divers or lowered from a boat gather comparatively less information.

HYDROLOGICAL

Natural stochastic occurrences, such as storms which are accompanied by intense current velocity, tidal fluctuations, and wave energy can influence kelp communities. For example, in addition to the associated temperature changes of the 1997-1998 El Niño in California, the event caused heavy storms along the West coast of North America which in turn, caused almost complete eradication of giant kelp forests in some areas (Edwards and Hernandez-Carmona 2000). Changes in climate will likely be connected to similar changes in hydrological characteristics. In addition to the direct effects on kelp, there are also indirect cascading effects on the associated animal community, food-web production, and trophic structure (Lehman 2004). Physical hydrological factors, such as current velocity, wave energy, and tidal fluctuations, should therefore be monitored because they can affect the success of kelp restoration projects.

Current Velocity and Tides

Current velocity and tides plays a significant role in the dispersal of kelp spores after they are released. Spore dispersal is important because it contributes to the colonization process and to genetic exchange among populations. High vertical currents may transport spores rapidly to the substratum where they settle before being dispersed (Denny and Shibata 1989). While this increases the probability of spore settlement in densities suitable for successful fertilization (Vogel 1991), it limits re-colonization of new areas. Vertical currents disperse spores into new locations, but very strong currents may also advect spores into unfavorable locations. In addition to currents and tides dispersing spores, many organisms, particularly those that attach to blades of kelp such as barnacles and tunicates, rely on tides and currents to help distribute nutrients throughout the water column so they can feed on these materials. Current velocity and direction, tides and other hydrodynamic variables should be measured to determine spore dispersal potential and nutrient transportation patterns.

Current velocity and fluctuating tides also influence the abundance of adult kelp and other macroalgae. Changes in the abundance of these plant species as a result of fluctuations in ocean conditions make it difficult to isolate and fully assess the impacts of potentially damaging human activities. The patchy geographic distribution also makes it difficult to detect adverse impacts to individual specimens at early stages.

Sampling and Monitoring Methods

There are various commercial instruments that can be used to measure currents and tides. For example, current velocity can be measured using current meters. The current meter is lowered into the water from a boat, dock, or pier using a wading rod or cable. Current velocity is measured by counting the number of revolutions of the bucket wheel over a certain time frame, then converting revolutions into water velocity using a rating chart (Anderson et al. 1996). Other technologies to measure current velocity exist and are discussed in chapter 9: Restoration Monitoring of SAV.

Tide gauges, which are mechanical devices that are usually placed on piers or pilings, can be used to record water levels (IOC 1985). The tide gauge consists of a data logger that reads and stores data from different sensors and a modem that communicates with a computer (IOC 1985). The water level sensor should be calibrated at regular intervals to ensure accurate water level measurements.

Acoustic Doppler flow meters can also be used to keep tidal flow by measuring velocity and particles moving through the water. Acoustic signals are transmitted from the instrument, then reflected off of particles and collected by a receiver. The signals received are then analyzed for frequency changes. The mean value of the frequency changes can directly relate to the average velocity of the particles moving through the water.

Wave Energy

Similar to currents, wave energy influences kelp structural and functional components. When severe storms occur, kelps may be uprooted and destroyed (Dayton 1985), as demonstrated by the large quantities found drifting at sea and washed up on beaches in winter. Severe wave action may also overturn the hard substrates (e.g., dislodge boulders, remove consolidated sediment, bury kelp with sediment) and destroy kelp, other macroalgae, and faunal communities (Foster and Schiel 1992). Increased wave energy also stirs up sediments, which smothers the kelp and reduces the amount of sunlight entering the water, thus reducing photosynthesis and restricting kelp growth. By monitoring the wave energy on kelp forest communities at both the surface and sediment surface, restoration practitioners will be better able to select plant species that are tolerant of such conditions, determine the time frame for restoration, and understand and address the physical impacts to the restored area. In addition to wave energy, the wave's angle of attack and the height at which the waves break should also be measured to assist in the restoration planting and monitoring design. Kelp and other macroalgae need to be planted in deep enough water to support them at low tide. This theoretical line is the shoreward limit of planting. Individual plants placed in shallow water will not survive the wave forces or will desiccate from too much exposure. Water depth should therefore be considered when selecting a restoration site and should be monitored relative to tidal cycles. Tide tables for the United States and its territories are available from NOAA at: http://tidesonline.nos.noaa.gov.

Measuring and Monitoring Methods

Wave energy effects on intertidal kelp and other macroalgae can be assessed using synchronized video, pressure sensors, and resistance wave gauges (Stevens et al. 2002). Accelerometers as well as displacement and force transducers can be used to measure macroalgal response to waves. Field measurements can then estimate forces and bending occurrences at the holdfast. It should be noted, however, that water depth variations throughout the tidal cycle affect blade accelerations and occurrences at the holdfast (Stevens et al. 2002).

Wave energy, average wave height, and periodicity can also be measured using wave buoys (Figure 10). Wave or current buoys are fixed weather stations in the ocean and record information about current conditions. Wave buoys measure wave heights, wave direction, and periodicity between waves using electronic sensors (Davies 1996). The buoys measure vertical and horizontal acceleration using accelerometers. Vertical acceleration determines wave height and horizontal acceleration determines wave direction (Davies 1996). These types of data are useful in kelp forest restoration design and implementation.

Various commercial instruments can also be used to measure depth and/or velocity as they relate to wave energy. Some instruments may be easy to install, operate, and maintain and include an ultrasonic velocity sensor with data

Figure 10. Retrieval of a current meter buoy. Photo courtesy of Commander John Bortniak, NOAA Corps. Publication of NOAA Central Library http://www.photolib.noaa.gov/corps/corp1716.htm

recording capabilities designed for both low and high flows found in kelp forests. The main advantage of electronic monitoring gear is the accuracy, consistency, and capability for real time data analysis.

Water Sources

Kelp and macroalgal communities can be modified by water quality. In many instances water entering coastal areas via terrestrial and industrial sources is polluted by excess nitrogen and phosphorus-based elements (Paine 1993). Sources responsible for changes in kelp and macroalgal communities include:

- Upland construction sites
- Increased freshwater discharges from channels and creeks that have been diverted for construction purposes
- Industrial discharges
- Oil pollution, which affects the functioning of both plant and animals (Williams et al. 1988)
- Agricultural and storm water runoff, and
- Sewage outfalls, drains, and contaminated rivers (Paine 1993)

Furthermore, increases in nutrient loading from pollutants result in phytoplankton blooms, causing reductions in light availability for kelps negatively affecting their growth.

The United States Environmental Protection Agency (USEPA) has developed a method to estimate toxicity of sewage effluent and receiving waters to kelp germination and development (see http://www.epa.gov/EERD/FB17_meth_905.pdf). Consideration should be given to the application of this method or a similar one before undertaking kelp reforestation. The *American Public Health Association's Standard Methods for the Examination of Water and Wastewater* also provides detailed field and laboratory procedures for analyzing water quality parameters such as nutrient concentrations, salinity, pH and dissolved oxygen that may be selected for use in restoration monitoring (Clesceri et al. 1998). Additional methods for assessing nutrient content in water samples are discussed further in chapters 9: SAV and 2: Water Column of this document.

CHEMICAL

Dissolved Oxygen

Most aquatic lifeforms need dissolved oxygen (DO) to survive. Factors responsible for dissolved oxygen in the water include the process of gas exchange with the atmosphere and the photosynthetic activity of plants such as macroalgae. Oxygen is then removed through respiration of living organisms and the decay of dead plants and animals. If the DO concentrations fall below the optimum level (hypoxia) needed to support plants and kelp associated organisms, then these plants and organisms may undergo stress. In some cases, excess nutrients may cause eutrophication which reduces oxygen levels to anoxic conditions (no oxygen). As a result of hypoxic or anoxic conditions, plant photosynthetic activity may be reduced affecting growth (Jackson 1977) and organisms, particularly fish that inhabit kelp forests and other macroalgae communities (see Chapter 2: titled "Restoration Monitoring of the Water Column" for a detailed discussion on low dissolved oxygen and its effects on fish).

Measuring and Monitoring Methods

There are various chemical and electronic methods that can be used to measure dissolved oxygen. Some of these methods are discussed in Chapter 2: Water Column, Chapter 4: Oyster Reefs, and Chapter 7: Soft Bottom Habitats of this document.

Salinity

Salinity plays a role in kelp and other macroalgal distribution and abundance. Salinity changes may occur due to freshwater inputs from industrial discharges, agricultural runoff, sewage discharges, and channel diversions. Construction activities may divert freshwater to areas occupied by kelp or discharge freshwater into kelp communities. As a result, salinity levels suitable for kelp growth may be altered, causing a decline in kelp productivity. Some studies have monitored germination inhibition of kelp *Ecklonia radiata* zoospores when exposed to sewage effluents and accompanying changes in salinity conditions (Burridge et al. 1999). Germination of zoospores responded negatively to the reduced salinity conditions when exposed for longer time periods.

Measuring and Monitoring Methods

Various hand-held commercial instruments can be used to measure salinity. Some electronic instruments calculate salinity in parts per thousand (ppt) based on temperature and conductivity readings. Hand-held refractometers on the other hand, measure salinity based on the salinity-dependent refraction index of light.

A conductivity, temperature, and depth (CTD) instrument (Figure 11) can also be used to measure salinity. The CTD instrument is lowered through the water column during which conductivity, temperature, and depth are continuously recorded. Salinity is then calculated based on conductivity because electric current passes readily through waters that have higher salinity levels. Salinity is usually given in practical salinity units (PSU), which is the same numerical value as parts per thousand.

Figure 11. CTD instrument. Photo courtesy of NOAA National Marine Fisheries Service, Southwest Fisheries Science Center.

FUNCTIONAL CHARACTERISTICS OF KELP AND OTHER MACROALGAE

Kelp forests fulfill important ecosystem functions, including:

Biological

- Provides habitat and shelter/refuge for many plants and animals
- Provides nursery and adult habitats that support species abundance and diversity
- Provides breeding grounds for fishes and marine mammals
- Provides feeding grounds for birds, fishes, invertebrates, and other marine organisms (Holbrook et al. 1990)
- Provides substrate for attachment

Physical

- Filters water and stabilizes sediment

By performing these functions, kelp forests are able to maintain plant and animal species diversity and abundance as well as support important recreational and commercial fisheries. If the algae are degraded in any way, the functioning of this habitat can be affected, such as its ability to support juveniles of marine organisms. Understanding how this habitat functions can help the practitioner select suitable parameters to track restoration efforts and achieve a naturally sustainable habitat. Monitoring should be performed to determine whether the habitat is functioning effectively and to track progress of the restoration project.

Methods to sample, measure, and monitor parameters affiliated with these functional characteristics are described below. This information is a limited account of the more important functions, as others exist and could also be valuable in monitoring certain restoration projects.

BIOLOGICAL

Provides Habitat and Shelter

Kelp forests and macroalgal habitats support diverse communities that contribute to primary productivity, as well as support biomass production, biodiversity, and a complex trophic structure (discussed in various sections throughout this chapter). These communities and their rocky substrate provide habitat for many different marine organisms. The three-dimensional structure of kelp forests can be divided into functional sub-habitats used by various organisms: The canopy is the region where the blades of the canopy-forming kelp species reach the surface. The midwater area is dominated by the stipes and lower blades of the canopy-forming algae. The complex structure of the benthic layer is comprised of the understory kelp, other algae, and the substrate. Some organisms associated with kelp forests can utilize all of these sub-habitats, but others are specialized in using certain areas. As species associated with kelp habitats vary among regions, practitioners should refer to the published literature to obtain species lists for the region in which restoration is being considered. The following will provide an overview of the general organism types associated with kelp beds as well as selected examples from various regions.

The canopy is mainly used by a variety of fish species which find shelter there from currents and predators that open water cannot provide. Adult fishes that utilize the canopy as habitat include:

Topsmelt (e.g., *Atherinops affinis)*
Kelp surfperch (e.g., *Brachyistius frenatus*)
Kelp pipefish (e.g., *Syngnathus californiensis*)

Kelp clingfish (e.g., *Rimicola muscarum*)
Rockfish (e.g., *Sebastes melanops)* (Figure 12)
Wrasses (e.g., *Semicossyphus pulcher, Oxyjulis californica*)
Damselfish (e.g., *Chromis punctipinnis)*, and
Bass (e.g.*, Paralabrax clathratus)*

(Note: species associated with each common name may vary by region or location.)

Many juveniles of these fish groups also utilize the canopy as habitat. In California, the giant sea bass (*Stereolepis gigas*) and pile surfperch (*Damalichthys vacca*) tend to be gregarious, swimming just under the canopy. A number of schooling fish, such as sardines, sometimes use the canopy. Invertebrates are less commonly seen in this upper level of the kelp forest, probably because the water motion prevents a good grasp to hold on to the kelp. Exceptions are pelagic species, such as jellies and shrimp, as well as some sessile organisms, such as diatoms, hydroids and bryozoans which can settle on the blades or stipes. Small gastropods (snails) can also be found on the blades of the canopy where they can remain aided by the strong suction adhesion of their foot. The canopy is also used as habitat by some marine mammals, especially sea otters which wrap themselves in kelp blades during resting periods to avoid drifting away or to protect themselves against predators such as white sharks (*Carcharodon carcharias),* killer whales (*Orcinus orca*), and bald eagles (*Haliaetus leucocephalus)* (Waite et al. 2002).

Fishes also dominate the organisms inhabiting the midwater zone of a kelp forest. Fish commonly found in the *Macrocystis pyrifera* beds of California are:

Kelp bass (e.g., *Paralabrax clathratus*)
Kelp surfperch (e.g., *Brachyistius frenatus*)
Rubberlip surfperch (e.g., *Rhacochilus toxoles*)
Blacksmith (e.g., *Chromis punctipinnis*)
Senorita (e.g., *Oxyjulis californica*) (Figure 13)
Halfmoon (e.g., *Medialuna californiensis)*
Giant kelpfish (e.g., *Heterostichus rostratus*)
Opaleye (e.g., *Girella nigricans), and*
Kelp clingfish (e.g., *Rimicola muscarum*)

Figure 12. Black rockfish. Photo courtesy of Kip Evans. Publication of NOAA Central Library. http://www.photolib.noaa.gov/sanctuary/sanc0805.htm

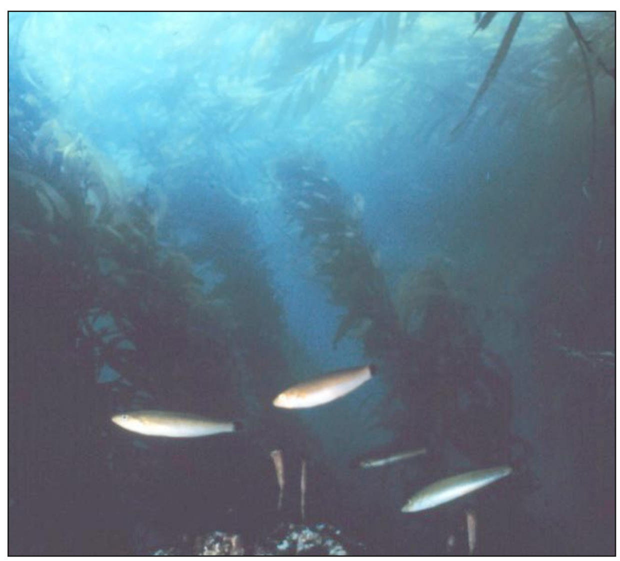

Figure 13. Senorita fish (*Oxyjulis californica*) in a giant kelp forest. Photo courtesy of Kip Evans. Publication of NOAA Central Library. http://www.photolib.noaa.gov/sanctuary/sanc0804.htm

(Note: species associated with each common name may vary by region or location.)

The halfmoon swims at midwater depth, occasionally feeding on sponges and bryozoans on the kelp stipes. The Rubberlip surfperch is also found at this midwater depth between the stipes. The clingfish attaches to kelp stipes using a suction cup and camouflages itself against predators. The most noticeable species associated with Southern California kelp forests is garibaldi (e.g., *Hypsypops rubicaunda*), with its bright orange adult color and high iridescent blue spots as juveniles. These individuals can be seen biting off pieces of kelp plants to feed on the bryozoa attached to the plant. The ocean whitefish (e.g., *Caulolatilus princeps*) wanders between the stipes several meters above the bottom and dives to the benthos to feed on the numerous crustaceans found there. Similar to the canopy, several invertebrates are able to utilize the structures provided by stipes and lower blades. These include hydroids, erect and encrusting bryozoans, and amphipods and other small crustaceans. Even larger gastropods and limpets can be found crawling up the stipes to graze. Some older stipes can also be heavily fouled (overgrown) by red algae.

At the bottom, kelp holdfasts, red algae, and the rock surface provide habitat for numerous mobile and sessile invertebrates and fishes. Sessile organisms found in this sub-habitat include:

Sponges
Hydroids
Tube dwelling polychaetes
Anemones (Figure 14)
Encrusting and erect bryozoans, and
Tunicates

Several polychaete worms and brittle stars make the interstitial spaces within kelp holdfast their protected home against predators. Such mobile invertebrates include:

Sea stars
Sea urchins
Sea cucumbers
Crabs and shrimp
Scallops
Gastropods
Nudibranchs, and
Limpets and abalone

Rockfish (*Sebastes* spp.) can be found in aggregations in the lower water depths around holdfast and between large rocks on the bottom. Gunnels, greenlings, sculpins, and ling cod also are common inhabitants of the benthos in kelp forests. Skates (Family Rajidae) and rays (Family Dasyatidae) can be seen moving along the bottom, and sanddabs (*Citharichthys* spp.) and halibut (e.g., *Paralichthys californicus*) are also common in this sub-habitat.

Provides Breeding and Nursery Grounds

Kelp and other macroalgae serve as breeding grounds for fishes, marine mammals, and sometimes birds. Several commercially important fish species (e.g., herring and rockfish)

Figure 14. Sea anemone (*Aiptasiidae*). Photo courtesy of Russel Bellmer, United States Fish and Wildlife Service.

use kelp forests as breeding grounds. Herring attach their eggs directly on the stipes of kelp. Sea otters have their young in kelp forest canopies, which provide shelter from strong currents and predators such as bald eagles and sharks. Birds usually do not use the subtidal kelp forest itself as breeding grounds, but intertidal kelp and other macroalgae can be important to some shorebirds and sea birds. Oystercatchers for instance, lay their eggs in macroalgal-dominated areas and sometimes shelter the eggs with algae. Kelp forests are also good nursery grounds because food is readily available for juveniles and the plants provide cover against predation. Some organisms such as fish, shrimps (Marliave and Roth 1995), and female otters with pups (Foster and Schiel 1985) commonly use kelp forests as nursery habitats.

Provides Feeding Grounds

Nutrients such as nitrate, nitrite, ammonia and phosphate are important for plant growth. Plants such as kelp and other macroalgal species absorb dissolved nutrients directly from the water through their blades which are then transported to other parts of the plant (e.g., stipe and holdfast).[5] Kelp and other macroalgae contribute substantial primary productivity and habitat complexity to the marine ecosystem (Dames and Moore 1977). Kelp plants, for example convert carbon dioxide (CO_2) and inorganic nutrients into organic matter that can be used as food by animals. When biological wastes and decayed plants and animals fall from the kelp forest into deep water, they form dissolved chemicals in the water. As water rises from deeper levels to the surface, they carry the dissolved chemical nutrients that are then used to nourish plants and animals amongst kelp. Thus, kelp form the base of the marine and estuarine food webs in the nearshore area where kelp dominates.

A variety of organisms uses kelp beds as feeding grounds on a number of different trophic levels. At the lowest trophic levels are the grazers, which utilize kelp directly by removing tissue from the algae. Grazers in kelp forests for example, include sea urchins, snails, and limpets. Although grazers usually are small in size compared to kelp, their feeding activities can have devastating effects. Urchins can graze at the stipes, causing dislodgement of entire kelp plants. Highly productive kelp forests were lost as a result of overgrazing by sea urchins in Nova Scotia (Johnson and Mann 1993) and the Aleutian Islands (Estes and Duggins 1995). Snails can occur in such large numbers that their grazing on the blades severely diminishes the photosynthetic capacity of kelp.

A large number of higher trophic level predators rely on these grazers and other omnivore invertebrates. Sea otters (Figures 15 and 16), lobsters, crabs, anemones, and fishes feed on sea urchins, snails, abalones, and limpets and play important roles in controlling these grazer populations (Barnes and Hughes 1993). Fish (e.g., lingcod, sculpins, and rockfish) commonly feed on small invertebrates and other fish that are present (Hogan and Enticknap 2003). Sea lions prey on fishes that live associated with kelp forests, and many diving birds, such as ducks and murres that feed in kelp forests.

Kelp is also the base of a second, detritus-based food web. A large portion of kelp biomass erodes through physical and bacterial actions and is supplied to the water column as detritus. This detritus is part of the diet of a large number of filter and deposit feeders, such as sponges, sea cucumbers, crustaceans, bryozoans, and ascidians, which in turn are food for predators such as nudibranchs, fishes, and crabs.

Provides Substrate for Attachment

Kelp provides attachment surfaces for many sessile and drifting life forms of various sizes. By attaching to kelp, species are able to obtain nutrients that are filtered by the blades. Some

[5] In the matrix at the end of this chapter, kelp's ability to "support nutrient cycling" is listed as a chemical function however the cycle of nutrients and, organisms that consume these nutrients relates to the biological functions of kelp and is discussed briefly under this section.

Figure 15. Sea otter wrapping in kelp blades. Photo courtesy of Russell Bellmer, Project Leader, United States Fish and Wildlife Service.

species such as barnacles (e.g., *Balanus* spp.), bryozoa (e.g., *Bugula* spp.), and foraminifera attach themselves to blades of kelp for support against currents. Some gastropods (e.g., turban snails) graze the fronds for epiphytic microalgae. The most common sessile organisms found in kelp forests include bryozoans, sponges (e.g., *Haliclona* spp.), tunicates (e.g., *Metandrocarpa* spp.), cup corals (e.g., *Balanophyllia* spp.), and anemones (e.g., *Epiactis* spp.).

Measuring and Monitoring Methods

Plant tissue analysis - Plant tissue analysis shows the nutrient status of plants at the time of sampling, i.e. whether there is adequate supply or deficiency of nutrients such as nitrogen and phosphorus that may affect kelp growth (Lyngby 1990). Kelp and other macroalgae wet samples are first collected and wet weight measured. The samples are then dried and grounded so that carbon and nitrogen concentrations in the plant tissues may be analyzed using a Carbon-Hydrogen-Nitrogen (CHN) elemental analyzer. Following acid digestion of the sample, phosphorus content can then be determined using spectrophotometric methods (Hernandez et al. 2001; Menendez et al. 2002).

Birds and marine mammals - Aerial surveys and direct counts along coastal and estuarine habitats can be used to monitor birds. Aerial

Figure 16. A sea otter feeding on a sea urchin. Photo courtesy of NOAA National Estuarine Research Reserve Collection. Publication of NOAA Central Library. http://www.photolib.noaa.gov/nerr/nerr0875.htm

surveys may be used to inventory shorebirds (Erwin et al. 1991) and monitor wintering populations (Morrison and Ross 1989). In addition, surveys are used to estimate relative abundance of migratory and wintering populations, as well as to assess population trends of migratory shorebirds. Direct counts are also used to estimate the number of shorebirds. In some cases, video cameras and aerial photography are used along with aerial surveys (Dolbeer et al. 1997). Photographs and other forms of data collected can be compared

Figure 17. Kelp attached to rocks on shore at low tide. Photo courtesy of Captain Albert E. Theberge, NOAA Corps (ret.). Publication of NOAA Central Library. http://www.photolib.noaa.gov/coastline/line2878.htm

to assess whether changes occurred in species numbers and distribution over time. In some cases, photographs may capture activities that may have occurred causing the reduction of one animal species and making conditions favorable for another. This can help the practitioner determine whether modifications can be made to the restoration project so that progress towards achieving a naturally sustainable habitat can be continued or whether the threat to the project is continuous and will continue to affect restoration progress.

Aerial surveys can also be used to count marine mammals. However, shore-based and boat-based surveys are usually more precise and allow for counting animals that spend considerable time underwater.

Fish and other species - Permanent transects and stations should be used to account for site variability and provide precise measurements of population dynamics where the major variable is time. Colored or otherwise marked transect lines are permanently attached to the seabed. Transect ends may be marked with a buoy to reduce search time. Permanent transects can be supplemented with random stations or transects. Transects and stations should also be located with Loran-C and GPS. The Loran-C system is a radio-navigation system that allows the user to accurately navigate and locate a position on the coastal waters and return to their starting position if needed. A global positioning system (GPS) is a satellite navigation system used to show an individual's exact position on Earth at anytime.

While there are numerous monitoring protocols, the following discussion focuses on those techniques most commonly used to gather data on population dynamics of selected kelp forest and other macroalgal associated organisms. Data collection should be replicated, and practitioners should consult a local biostatistician to ensure that the sampling design is not pseudoreplicated (i.e., replicate transects have to be spatially separated). Sampling and monitoring should also be replicated within a year to account for seasonal changes.

Typical sampling and monitoring methods for kelp-associated organisms include:

- Plankton nets (to sample larval fish) (Figure 18)
- Quadrat counts and percent cover estimates
- Swath transect counts
- Random point observations
- Roving diver fish counts, and
- Video fish transects (50 meters) in the kelp canopy, water column, and benthos

Described below are just a few of the many methods that can be used to sample and monitor fish and other mobile macroalgae associated species.

Plankton[6] nets - Plankton nets are used to capture plankton floating in the water column. These nets have a long funnel shape net that is used to capture different plankton sizes by changing the mesh size of the net and yet allowing water to filter through. These nets can

Figure 18. A diver deploys a plankton net in a kelp forest to collect larval fish. Photo courtesy of NOAA Office of Oceanic and Atmospheric Research, National Undersea Research Program. Publication of NOAA Central Library. http://www.photolib.noaa.gov/nurp/nur05519.htm

[6] The passively floating or weakly motile aquatic plants (phytoplankton) and animals (zooplankton).

be deployed by hand over the side of a boat or attached by hinges behind the boat and towed to collect plankton samples.

Quadrat counts and percent cover estimates - These measures can be used to efficiently and reliably assess the diversity and abundance of sedentary species and to record changes over time. An established set of species and other metrics can be assessed by divers in quadrats that are placed in fixed or random points along the transects. White plastic slates or clipboards with underwater paper are useful for notes. These measurements can be combined with the quantitative data obtained about kelp abundance (e.g., stipe counts, percent cover) and substrate. The size of the quadrat depends on the location and density of organisms. Usually, 50x50 centimeter or 1x1 meter quadrats provide sufficient area while still being manageable for a diver. It is also useful to work with three-sided quadrats, which can be easily placed on the bottom around tall kelp. Quadrats are commonly made out of PVC piping, but they should be weighted to avoid floating upward.

Swath transects - A certain width (one or two meters) on each side of the transect line is observed and fishes identified and counted. As different fish species may inhabit different sub-habitats of the kelp forest, these swaths can be repeated in midwater and under the canopy. If available, size frequency distributions can be used to estimate population age structure and to identify and monitor recruitment cohorts. Direct diver observations have often proven to be more reliable than video transects, but video can provide valuable support for fish observations if water clarity is good.

PHYSICAL

Filters Water and Stabilizes Sediments

Kelp and other macroalgae assist in filtering the water column by reducing wave energy and stabilizing sediments (discussed in various sections throughout this chapter). The kelp blades, as well as the holdfast (thallus), have the ability to slow water movement allowing sediments to accumulate on the benthic surface. This process helps to reduce the potential for erosion of shorelines by reducing wave energy.

CHEMICAL

The chemical characteristics of kelp and other macroalgae that are presented within the matrices, have been discussed within the structural and functional characteristics discussed above, particularly under sections titled “Physical” and “Dissolved Oxygen”.

PARAMETERS FOR MONITORING STRUCTURAL/FUNCTIONAL CHARACTERISTICS

The following matrices present parameters for restoration monitoring of the structural and functional characteristics of kelp and other macroalgae. These matrices are not exhaustive, but represent those elements most commonly used in such restoration monitoring strategies.

These parameters have been recommended by experts in kelp restoration as well as in the literature on kelp and other macroalgae restoration and ecological monitoring. Parameters with a closed circle (●) should be considered in monitoring restoration performance. Parameters with an open circle (❍) may also be measured, depending on specific restoration goals.

Parameters to Monitor the Structural Characteristics of Kelp and Other Macroalgae

Parameters to Monitor	Structural Characteristics												
	Biological	Habitat created by animals	Habitat created by plants	**Physical**	Sediment grain size	Light availability/Turbidity	**Hydrological**	Current velocity	Tides/Hydroperiod	Water sources	Wave energy	**Chemical**	pH, salinity, toxics, redox, Dissolved oxygen
Geographical													
Acreage of habitat types		○	●										
Biological													
Plants													
Species, composition, and % cover of:													
Algae			●										
Epiphytes			○										
Canopy aerial extent and structure			○										
Interspersion of habitat types		●	●										
Plant height			○										
Seedling survival			○										
Hydrological													
Physical													
Photosynthetically active radiation (PAR)[7]						●							
Secchi disc depth						●							
Shear force at sediment surface								○			○		
Water column current velocity								●					
Water level fluctuation over time									○				
Water temperature													●
Chemical													
Dissolved oxygen													○
pH													○
Salinity									○				●
Toxics													○
Soil/Sediment													
Physical													
Geomorphology (slope, basin cross section)									●				
Organic content					○				○				
Percent sand, silt, and clay					○								
Chemical													
Pore water nitrogen and phosphorus										○			

[7] Measured at canopy height and substrate surface.

Parameters to Monitor the Functional Characteristics of Kelp and Other Macroalgae

Parameters to Monitor	Contributes to primary production	Provides breeding grounds	Provides feeding grounds	Provides nursery areas	Provides habitat	Provides substrate for attachment	Supports complex trophic structure	Supports biomass production	Supports biodiversity	Reduces erosion potential	Reduces wave energy	Modifies chemical water quality	Modifies dissolved oxygen	Supports nutrient cycling
	Biological									**Physical**		**Chemical**		
Geographical														
Acreage of habitat types	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Biological														
Plants														
Species, composition, and % cover of:														
Algae	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Epiphytes	❍		❍				❍	❍	❍				❍	❍
Canopy aerial extent and structure		❍	❍	❍	❍	❍		❍	❍		❍			
Interspersion of habitat types		❍	❍	❍	❍		❍	❍	❍	❍	❍	❍		❍
Plant health (herbivory damage, disease[8])														
Plant weight (above and/or below ground parts)	❍							❍						
Nutrient levels in algal tissues (nitrogen, phosphorus)	❍		❍					❍						
Rate of canopy closure												❍		❍
Seedling survival[8]	❍							❍						
Stem density				❍	❍	❍❍	❍			❍	❍			
Biological														
Animals														
Species, composition, and abundance of:														
Birds														
Fish		❍	❍	❍	●		❍	❍	❍					
Invertebrates		❍	❍	❍	●		❍	❍	❍					

[8] If the whole community is destroyed by disease or lack of seedling survival, all vegetation-related functions will be impaired.

Parameters to Monitor the Functional Characteristics of Kelp and Other Macroalgae (cont.)

Parameters to Monitor	Biological: Contributes to primary production	Provides breeding grounds	Provides feeding grounds	Provides nursery areas	Provides habitat	Provides substrate for attachment	Supports complex trophic structure	Supports biomass production	Supports biodiversity	Physical: Reduces erosion potential	Reduces wave energy	Chemical: Modifies chemical water quality	Modifies dissolved oxygen	Supports nutrient cycling
Hydrological														
Physical														
Photosynthetically active radiation (PAR)	●							●						
Secchi disc depth	●							●						
Trash			❍											
Water column current velocity										❍				
Water level fluctuation over time		❍	❍	❍	❍					❍			❍	❍
Chemical														
Dissolved oxygen		❍		❍			❍		❍			❍	❍	❍
Toxics		❍	❍	❍								❍		
Soil/Sediment														
Physical														
Geomorphology (slope, basin cross section)		●	●	●	●	●			●	●		●	●	
Sediment grain size (OM[9]/sand/silt/clay/gravel/cobble)						❍		❍		❍	❍	❍	❍	❍

[9] Organic matter.

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APPENDIX I: KELP AND OTHER MACROALGAE ANNOTATED BIBLIOGRAPHY

This annotated bibliography contains summaries of restoration case studies and basic ecological literature. It is designed to provide restoration practitioners with examples of previous restoration projects as well as overviews of papers from the ecological literature that offer more detail than that covered in the associated chapter. Entries are presented from both peer reviewed and grey literature. They were selected through extensive literature and Internet searches as well as input from reviewers. They are not, however, a complete listing of all of the available literature. Entries are arranged alphabetically. Wherever possible, web addresses or other contact information has been included in the reference to assist readers in easily obtaining the original resource. Summaries preceded by the terms '*Author Abstract'* or *'Publisher Introduction*' or similar descriptors were taken directly from their original source. Summaries without such descriptors were written by the author of the associated chapter.

Beissinger, S. R. 1995. Population trends of the marbled murrelet projected from demographic analyses, pp. 385-393. In Ralph, C. J., G. L. Hunt Jr., M. G. Raphael and J. F. Piatt (eds.), Ecology and Conservation of the Marbled Murrelet. Technical report - Pacific Southwest Research Station 152.

Author Abstract. This paper discusses monitoring of marbled murrelet populations amongst kelp beds. Researchers used a demographic model of the marbled murrelet to investigate possible population trends and factors that may influence them. The model included field data on juvenile ratios that were collected near the end of the breeding season and rectified for date of census, to estimate fecundity. See publication for additional information on techniques used. Murrelet survivorship estimates were based on comparative analyses of allometric relationships from 10 species of alcids. Results showed that the juvenile ratios were commonly low but were higher from shore or in kelp beds than conducted offshore (<5%). Annual survivorship was correlated to alcids body size. Marbled murrelet survivorship was predicted to be 0.845 and range to 0.90. The expected annual population growth rate was estimated based on combinations of fecundity and survival. This indicated that under all combinations murrelet populations were expected to decline. Based on data, rates of decline are predicted to be 4-6 percent per year, but the rate of decline could be twice as large. Results were based on factors affecting murrelet population growth, and the use of juvenile ratios for monitoring murrelet populations.

Burridge, T. R., M. Karistianos and J. Bidwell. 1999. The use of aquatic macrophyte ecotoxicological assays in monitoring coastal effluent discharges in southern Australia. *Marine Pollution Bulletin* 39: 89-96.

Author Abstract. Germination inhibition of zoospores of the aquatic, brown algal macrophyte *Ecklonia radiata* was employed to assess the toxicity of sewage effluents under short to long-term exposure and under modified salinity conditions. The rate of germination inhibition was determined for exposure times between 2 and 48 h in salinity modified and unmodified regimes and under reduced salinity conditions alone. The results indicated that rate of germination inhibition increased with duration of exposure to sewage effluents and to salinity reduction alone, and that response to the effluents may be enhanced under conditions of reduced salinity. Whilst the effect of primary treated effluent was primarily that of toxicity, secondary treated effluent effects appeared to be primarily that of reduced salinity although at a greater rate than would be expected for salinity reduction alone. The assay is suggested to provide a mechanism for monitoring sewage effluent quality and to monitor potential impacts of sewage effluent discharge on kelp communities in southern Australia.

Burridge, T., S. Campbell and J. Bidwell. 1999. Use of the kelp *Ecklonia radiata* (*Laminariales: Phaeophyta*) in routine toxicity testing of sewage effluents. *Australasian Journal of Ecotoxicology* 5: 133-140.

Author Abstract. This paper investigates the effect of primary and secondary treated sewage effluents on reproductive phases of the life cycle of the marine macrophyte (kelp) *Ecklonia radiata. Ecklonia radiata* is a major primary producer in near-shore medium to high energy habitats and as a benthic organism is subject to long-term chronic exposure to coastal effluent. See publication for additional information on methods used for toxicity testing with the use of kelp. Inhibition of germination and reduction in growth rate of gametophytes are used as end points in bioassays. For primary treated effluent, germination was significantly inhibited at 1% effluent while growth was significantly inhibited at 4% effluent. Responses to secondary treated effluent indicated that for both endpoints the principal effect was related to reduce salinity. For one of the secondary treated effluents and for both bioassays there was no significant difference in response from salinity reduction bioassays, and for the second effluent type toxicity was expressed at 40% to 60% effluent. The results indicate that both bioassays offer great potential for the routine screening of effluent quality. Both bioassays and especially the germination inhibition bioassay are simple to conduct, show high reproducibility and are ecologically relevant.

Bushing, W. W. 2000. Monitoring the persistence of Giant kelp around Santa Catalina island using a geographic information system. *Journal of Phycology* 36:9-10.

Author Abstract. Geographic information systems (GIS) facilitate monitoring and analysis of population distributions at spatial and temporal scales differing from those employed in conventional field monitoring. This study utilizes a GIS-based gap analysis of a network of marine reserves around Santa Catalina Island relative to the regional ecology, disturbance regime, and persistence of Giant kelp (*Macrocystis pyrifera*), a keystone species in the nearshore, marine environment. Catalina's orientation and greatly-dissected coastline create diverse microhabitats with respect to storm exposure, temperature, light regime and topographic factors. GIS overlay methods applied to multi-temporal kelp distribution maps generated a model representing the spatial "persistence" of kelp. Correlations between the kelp's geographic distribution and persistence, the disturbance regime and physical variables conferring resistance to or recovery from it were drawn. This analysis identified regions of persistent kelp under disturbance regimes markedly different from those in the existing reserves, suggesting the designation of additional reserves in unprotected areas is ecologically warranted.

Christie, H., S. Fredriksen and E. Rinde. 1998. Regrowth of kelp and colonization of epiphyte and fauna community after kelp trawling at the coast of Norway. *Hydrobiologia* 375-376:49-58.

Author Abstract. Off the Norwegian coast the kelp plants form dense forests, 1-2 m high, and house a large number of epiphytes and associated invertebrates. Researchers sampled kelp, epiphytes, and holdfast (thallus) (hapteron) fauna at two different regions in untrawled kelp forest and at sites trawled different number of years ago. Researchers examined the rate of kelp regrowth after trawling, and in what time scale the associated flora and fauna colonize the trawled areas. See publication for additional information on techniques used. Trawling removed adult kelp plants (the canopy plants), while small understory kelp plants were left undisturbed. Results showed that under improved light conditions recruits made the new generation of canopy-forming kelp plants that exceeded a height of 1 m within 2-3 y. Percent cover, abundance and number of epiphytic species increased with time following trawling, but epiphytic communities were not totally re-established before the next trawling episode. Colonization of most species of fauna inhabiting the kelp holdfast (thallus) was found as early as one year after trawling. However, increasing size of the habitat by age of kelp allowed both individuals and species numbers to increase. Slow colonization rate by some species might be due to low dispersal potential. Researchers concluded that due to a higher maximum age and size of kelp plants in the northernmost region studied, restoration of kelp and kelp forest community was slower there.

Cole, R. G. and C. Syms. 1999. Using spatial pattern analysis to distinguish causes of mortality: an example from kelp in north-eastern New Zealand. *Journal of Ecology* 87:963-972.

Author Abstract. Spatial analysis techniques were used to differentiate between climate-induced and pathogen-induced mass mortalities of the kelp *Ecklonia radiata* in north-eastern New Zealand. We predicted that climate-induced effects would generate broad-scale patterns, whereas pathogen-induced mortality would be traceable among neighbouring thalli. Spatial autocorrelation analysis was performed on the proportion of *E. radiata* affected by dieback in quadrats during an initial mortality event in 1991. The absence of any consistent spatial scale of affected thalli between 10 and 100 m suggested that small-scale spread of an agent might be occurring. Individual thalli were therefore mapped at two sites during a subsequent mortality event in 1992/93, and the degree of damage recorded. Spatial analyses found little evidence of aggregation of either intact or affected thalli at scales of 1-150 cm. The relative spatial patterns of healthy and affected plants in mapped quadrats during the 1992/93 mortality provided little evidence of spatial association or repulsion between these broad damage categories. The large-scale mortality of 1992/93 was consistent with a physiological response to broad-scale light deprivation, although other agents, perhaps both a virus and amphipod grazing, might also have been involved. Potentially complex interactions among the candidate agents render interpretation of the spatial patterns difficult.

Dayton, P. K. 1985. The structure and regulation of some South American kelp communities. *Ecological Monographs* 55:447-468.

The goal of the study was to assess how physical stress and herbivores influence giant kelp (*Macrocystis pyrifera)* distribution, abundance, size frequency, and mortality in the southeast Pacific. Data was collected by scuba diving and belt transects. Transects were placed beside isobaths in order to quantify depth effects. In some cases photographs were used to collect data. Results showed that *Loxechinus* was limited by larval recruitment in the far south, sedimentation, fresh water protected fjords, and by fishing in the northern areas. Significantly low *Loxechinus* densities were due to reduced kelp populations. Kelp mortality results from drifting *Macrocystis* plants. Based on studies, kelp populations seemed restricted by physical factors in the fjords and *Loxechinus* grazing in most areas.

Dean, T. A. and S. C. Jewett. 2001. Habitat-specific recovery of shallow subtidal communities following the *Exxon Valdez* oil spill. *Ecological Applications* 11:1456-1471.

Researchers compared *Exxon Valdez* oil spill impacts within kelp and eelgrass communities and examined recovery of these communities over a period of ten years after the spill. Methods used to assess oil spill impacts was an After Control Impact Pairs (ACI-P) design (Green 1979, Osenberg and Schmitt 1996). See publication for additional information on methods used. Observations revealed that impacts were mostly in sheltered bays that were exposed to heavy oiling. Results showed that within a year after the spill, total polycyclic aromatic hydrocarbons (TPAHs) concentrations were higher, negatively affecting organisms in both communities but eelgrass organisms were affected more severely than those in kelp beds. Overall recovery was slower in eelgrass than in kelp habitats. Within six years after the spill, approximately 80% of the groups in eelgrass beds showed little signs of recovery. However, kelp beds recovered within two years. Researchers stated that data supported previous findings that impacts due to large oil spills are persistent.

Dean, T. A. and D. Jung. 2001. Transplanting Giant Kelp (*Macrocystis pyrifera*) onto Artificial Reefs: The San Clemente Reef Mitigation Project, pp. 31-34. In Jewett, S. C. (ed.), Cold Water Diving for Science. University of Alaska Sea Grant, Fairbanks AK.

Author Abstract. Southern California Edison Co. (SCE) is required to build a 300 hectare (150 acre) artificial reef for the purpose of mitigating the impacts of the San Onofre Nuclear Generating Station on nearby kelp bed communities. One of the primary mitigation requirements is that the reef supports a stable population of moderate to high density of giant kelp (*Macrocystis pyrifera*). As an initial step in reef development, SCE constructed an experimental reef in fall 1999 to test several reef designs that are being considered for the larger mitigation effort (Deysher et al. 1998, in press). The experimental reef consists of fifty-six modules, each measuring approximately 40 x 40 m, which were placed on a sandy bottom at depths of 12 to 15 m off San Clemente, CA. Half the modules were constructed of quarry rock, the other half were constructed of waste concrete, and all were low relief (less than 1 m). In summer 2000, we transplanted juvenile giant kelp (*M. pyrifera*) onto 14 of these modules (seven quarry-rock and seven concrete) to test transplanting as a potential means of enhancing and maintaining moderate to high densities of kelp. In this paper we describe the diving techniques used in anchoring these plants onto concrete or rocks. The kelp used in transplanting were initially reared in the laboratory using methods described in Foster et al. (1985) and then transplanted onto the reefs. Divers collected sporophylls (spore-bearing blades) from the base of adult kelp and brought these back to the laboratory. There, we released spores from the blades and inoculated 0.6 cm diameter x 10 cm long nylon lines with the spore solution. The lines were cultured in the laboratory for about three to five weeks until a dense culture of small kelp plants (about 1 mm to 5 mm in height) was visible. The lines were then taken to reef sites and anchored onto rocks or concrete.

Dean T. A., J. L. Bodkin, S. C. Jewett, D. H. Monson and D. Jung. 2000. Changes in sea urchins and kelp following a reduction in sea otter density as a result of the *Exxon Valdez* oil spill. *Marine Ecology Progress Series* 199:281-291.

Author Abstract. Interactions between sea otters *Enhydra lutris*, sea urchins *Strongylocentrotus* *droebachiensis*, and kelp were investigated following the reduction in sea otter density in Prince William Sound, Alaska, after the *Exxon Valdez* oil spill in 1989. At northern Knight Island, a heavily oiled portion of the sound, sea otter abundance was reduced by a minimum of 50% by the oil spill, and from 1995 through 1998 remained at an estimated 66% lower than in 1973. Where sea otter densities were reduced, there were proportionally more large sea urchins. However, except in some widely scattered aggregations, both density and biomass of sea urchins were similar in an area of reduced sea otter density compared with an area where sea otters remained about 10 times more abundant. Furthermore, there was no change in kelp abundance in the area of reduced sea otter density. This is in contrast to greatly increased biomass of sea urchins and greatly reduced kelp density observed following an approximate 90% decline in sea otter abundance in the western Aleutian Islands. The variation in community response to a reduction in sea otters may be related to the magnitude of the reduction and the non-linear response by sea urchins to changes in predator abundance. The number of surviving sea otters may have been high enough to suppress sea urchin populations in Prince William Sound, but not in the Aleutians. Alternatively, differences in response may have been due to differences in the frequency or magnitude of sea urchin recruitment. Densities of small sea urchins were much higher in the Aleutian system even prior to the reduction in sea otters, suggesting a higher rate of recruitment.

Dean, T. A., K. Thies and S. Lagos. 1989. Survival of juvenile giant kelp: The effects of demographic factors, competitors, and grazers. *Ecology* 70:483-495.

Researchers examined survival patterns of juvenile giant kelp (*Macrocystis pyrifera*). Kelp was measured using quadrats and transects. Transects were marked permanently with steel bars that were forced into the bottom sediment. Juvenile kelp or larger were tagged along each transect. Researchers then mapped the location of each plant by recording the plant's distance from the center line. Surveys were performed to determine the presence and absence of each plant tagged, determined the bulk density of survivors, tagged and mapped newly recruited plants. Data collected showed survival was low in zones wherever white sea urchins (*Lytechinus anamesus*) were abundant or where there was an overlying canopy of adults. At other sites, the density of recruits that survived varied, and the amount of juveniles that survived negatively correlated with the number of recruits. In addition, algal competitors (*Pterygophora californica* and *Cystoseira osmundacea*), red sea urchins (*Strongylocentrotus franciscanus*) and substrate distributions had no significant effect on juvenile kelp survival.

Dean, T. A. and L. E. Deysher. 1994. Kelp restoration and establishment techniques. *Bulletin of Marine Science* 55:1333.

Author Abstract. This paper discusses the growth of Giant kelp on natural and artificial reefs for enhancing reef productivity and providing structure for fish and invertebrates. Researchers mention that transplanting of juvenile kelp appears most cost effective. The young plants can be collected after recruitment or can be reared in the laboratory. See publication for additional information on techniques used. Researchers "seed" kelp spores onto nylon lines, in the laboratory and grow plants to a small (1 mm) sporophyte stage. Sporophytes on lines however can be reared to a larger size (50 cm to 1 m in length) in the laboratory or in field "grow out" areas. Results showed that field "grow out" proved more successful and cost effective than laboratory grow out. Juvenile kelp (50 cm to 1 m) was transplanted on more than 20 occasions with success. Results also showed that approximately 90% of field "grow outs" provided large numbers of sporophytes for transplanting. Researchers concluded that in 3-5 months average height is about 50 cm and can then be transplanted to substrates. The survival rate is expected to be high (>80%) when planted in appropriate habitats.

Dean, T. A., M. S. Stekoll and R. O. Smith. 1996. Kelps and oil: The effects of the *Exxon Valdez* oil spill on subtidal algae, pp. 412-423. In Rice, S. D., R. B. Spies, D. A. Wolfe and B. A. Wright (eds.), Proceedings of the *Exxon Valdez* Oil Spill, American Fisheries Society Symposium 18. AFS Bethesda, MD.

Author Abstract. This study examined possible changes in the subtidal macroalgal populations as a result of the *Exxon Valdez* oil spill. The abundance and size distribution of dominant subtidal algae were measured in Prince William Sound one year after the spill. Population density, biomass, and cover were compared between oiled and control sites within each of three habitats: sheltered bays, moderately exposed points, and very exposed points with a surface canopy of *Nereocystis luetkeana*. Dominant macroalgae in these habitats were the kelps *Agarum cribrosum, Laminaria saccharina*, *L. groenlandica,* and *N. luetkeana.* There were no differences in the total density, biomass, or percentage cover of macroalgae between oiled and control sites. However, at least one of the dominant kelp species within each habitat was more abundant at the oiled sites. In addition, there were generally more small plants at oiled sites, suggesting recent recruitment or slower growth there. Recruitment at oiled sites may have been indicative of recovery from recent oil-related disturbance. Although these data suggest possible injury to kelps as a result of the spill, there were no apparent long-term impacts on subtidal populations of macroalgae.

De Vogelaere, A. P. and M. S. Foster. 1994. Damage and recovery in intertidal *Fucus gardneri* assemblages following the *Exxon Valdez* oil spill. *Marine Ecology Progress Series* 106:263-271.

Author Abstract. In March 1989, the *Exxon Valdez* spilled over 10 million gallons (ca 38 million l) of crude oil into Prince William Sound, Alaska, USA. The spill was followed by massive clean-up using hot seawater at high pressure as well as other mechanical and chemical techniques. Researchers studied initial damage and subsequent recovery in the upper margin of the *Fucus gardneri* assemblage on protected shores by comparing sites that were unoiled, oiled and cleaned with hot water at high pressure, and oiled but less intensely cleaned. See publication for additional information on method used. *F. gardneri* cover averaged 80 % on unoiled sites but <1 % on all oiled and cleaned sites 18 mo after the spill. The abundances of barnacles, littorine snails and limpets varied among sites and species, and this variation was associated in part with differences in their life histories. *F. gardneri* cover was still extremely low on oiled and cleaned sites 2.5 yr after the spill. Holdfasts (thallus) that persisted after cleaning did not re-sprout. *F. gardneri* recruitment was lowest at intensely cleaned sites, and most recruits occurred in cracks near adults. Recruits were less abundant under adult canopies but placing canopies over recruits did not decrease their survivorship over 5 mo. Natural weathering of tar was rapid, with most marked patches gone in less than 1 yr.

Ebeling, A. W., D. R. Laur and R. J. Rowley. 1985. Severe storm disturbances and reversal of community structure in a southern California kelp forest. *Marine Biology*. 84: 287-294.

Author Abstract. Regular observations made over a period of 5 yr in 4 permanent transects provided data on plant, sea urchin, and fish densities which indicate that 2 unusually severe winter storms in 1980 ("Storm I") and 1983 ("Storm II") had different effects on a southern California kelp-forest community. Storm I removed all canopies of the giant kelp *Macrocystis pyrifera*, but spared most understory kelps, mainly *Pterygophora californica*. Hence, the previously large accumulation of detached drift kelp, mostly *M. pyrifera,* disappeared. Denied their preferred diet of drift kelp, the sea urchins *Strongylocentrotus franciscanus* and *S. purpuratus* then emerged from shelters to find alternative food. Without effective predators, they consumed most living plants, including the surviving understory kelps. This weakened the important detritus-based food chain. In 1983, Storm II reversed the process by eliminating exposed urchins, while clearing rock surfaces for widespread kelp settlement and growth.

Edwards, M. S. and G. Hernandez-Carmona. 2000. Scale-dependent patterns of disturbance and recovery in Giant kelp forests. *Journal of Phycology* 36:540-544.

Author Abstract. We studied spatial variability in giant kelp (*Macrocystis pyrifera*) forests at 84 sites along the West coast of North America in order to assess the impacts of the 1997-98 El Niño. Our sites spanned the geographic range of giant kelp in the Northern Hemisphere and were surveyed just before, immediately following, several months after, more than one year after, and nearly two years after the El Niño. Interspersion of sample units allowed us to compare the effects of this disturbance among spatial scales ranging from a few meters to more than a thousand kilometers. Variance components analyses revealed that El Niño shifted the relative importance of factors that regulate giant kelp communities from factors acting at the scale of a few meters (local control) to factors operating at hundreds of kilometers (regional control). Moreover, El Niño resulted in a near-to-complete loss of giant kelp populations throughout nearly two-thirds of the species' range. Evaluation of these effects along with oceanographic data (at the "appropriate" spatial scales), along with closer examination of giant kelp populations in the most severely impacted region (Baja) suggested that the among-region differences in giant kelp survival was due, at least in part, to El Niño-induced differences in ocean climate. Giant kelp recovery following El Niño was also scale-dependent, but driven by factors different from those of the disturbance. Here, we present results for several species of macroalgae in an attempt to relate the importance of El Niño to that of other processes in creating scale-dependent patterns of variability.

Gerard, V. A. 1984. The light environment in a giant kelp forest: Influence of *Macrocystis pyrifera* on spatial and temporal variability. *Marine Biology* 84:189-195.

Practitioners measured quantum irradiance at numerous depths in giant kelp *M. pyrifera* (L.) C. Agardh forests in southern California throughout summer of 1983. Quantum irradiance measurements were made using two quantum scale profiling systems along with underwater sensors. The sensor was used to measure irradiance at the surface. Data were documented simultaneously from the sensors via IMS International computer and Biospherical Instruments interface hardware and software. Light transmission was also measured through each canopy blade using underwater sensors. Results showed that maximum irradiance reduction occurred in the top 1 m of the water column where the kelp fronds produced surface canopies. Average irradiances were documented at 1 m depth below kelp canopies beneath adequate sunlight levels at surface conditions. Light penetration correlated with canopy density, however, was greater than transmission through individual kelp blades.

Graham, M. H., C. Harrold, S. Lisin, K. Light, J. M. Watanabe and M. S. Foster. 1997. Population dynamics of Giant kelp *Macrocystis pyrifera* along a wave exposure gradient. *Marine Ecology Progress Series* 148:269-279.

Author Abstract. Sporophyte recruitment, holdfast (thallus) growth, and mortality of Giant kelp *Macrocystis pyrifera* were measured seasonally on permanent transects at three sites (protected, intermediate, and exposed) along a wave exposure gradient on the Monterey Peninsula, central California (USA) between 1988 and 1991. The constant presence of cold, nutrient-rich water and the relative absence of other kelps and large grazers allowed the dynamics of *M. pyrifera* populations to be examined under conditions in which wave exposure was highly variable and influences of other abiotic and biotic factors were minimized. Recovery of *M. pyrifera* populations from decreased adult density (presumably due to storm-induced mortality; adult density was negatively correlated with storm activity) was a two-stage process requiring the establishment of juvenile populations and conditions suitable for juvenile growth to adult size. Sporophyte recruitment was negatively correlated with *M. pyrifera* canopy cover, and thus appeared to be related to irradiance. Recruitment was low and continuous under a temporally stable *M. pyrifera* canopy at the protected site. At the intermediate and exposed sites, canopy cover was more variable, canopy loss was greater, and durations of low canopy cover were longer than at the protected site, resulting in episodic sporophyte recruitment.

Hernandez-Carmona, G., O. Garcia, D. Robledo and M. Foster. 2000. Restoration techniques for *Macrocystis pyrifera* (Phaeophyceae) populations at the southern limit of their distribution in Mexico. *Botanica Marina* 43:273-284.

Author Abstract. Following the 1982-83 El Niño, *Macrocystis pyrifera* (L.) C. Agardh, forests disappeared throughout their range in Baja California. The giant kelp forests subsequently recovered within this range except at their extreme southern limit, a region encompassing 50 km of coastline with a former giant kelp standing stock of 28,000 wet tons. Two techniques were tested to restore these forests: juvenile transplantation and seeding with sporophylls. For transplanting, juvenile *M. pyrifera* sporophytes were attached to *Eisenia arborea* stumps seasonally over a two-year period. Average survival of transplants ranged from 7% in spring to 41% in winter. After two years, the average number of basal fronds per plant increased from 2 to 64 per plant and surface fronds from 0 to 34 per plant. Average frond growth rate of the transplants ranged from 8.1 cm day^{-1} in summer to 10.8 cm day^{-1} in winter. No significant differences in growth rate were found among treatments (seasons) for the transplants, but control plants showed a seasonal variation, with higher frond growth rates in winter (13.3 cm day^{-1} and spring (9.3 cm day^{-1} and lower in summer (4.4 cm day^{-1}). The seeding technique was tested in a fully orthogonal-block design with three factors with two levels (factors: ± sporophylls addition, ± *Eisenia arborea* and ± understory algae). *Macrocystis pyrifera* recruitment occurred only in treatments with added sporophylls. The highest recruitment occurred where all algae were removed from the bottom, followed by the treatments without understory algae but with *Eisenia arborea*. Results suggest that a lack of spores and the presence of understory algae were the main factors inhibiting *Macrocystis pyrifera* recruitment in the area. Lower sea water temperatures and high nutrient concentrations occurred in spring and high temperatures and low nutrients in summer suggesting, as in southern California, an inverse relationship between these two factors. The results suggest a combined approach of transplanting juveniles and seeding during spring would be most effective for restoring the *M. pyrifera* forests.

Karsten, U., K. Bischof and C. Wiencke. 2001. Photosynthetic performance of Arctic macroalgae after transplantation from deep to shallow waters. *Oecologia* 127:11-20.

Author Abstract. Transplantation experiments conducted in the Arctic Kongsfjord (Spitsbergen) in summer 1997 investigated the effects of various types of filtered natural radiation (solar, solar without UV-B, solar without UV-A/B) on photosynthesis of various macroalgae. Two brown algal species (*Laminaria solidungula, Saccorhiza dermatodea*) and four red algal species (*Palmaria palmata, Phycodrys rubens*, *Phyllophora truncata, Ptilota plumosa*) were collected from deeper waters, kept in UV-transparent plexiglass tubes wrapped with different spectral cut-off filter foils and positioned at fixed depths in shallow waters for 7-9 days. At regular intervals, chlorophyll fluorescence of photosystem II (optimum quantum yield, Fv/ Fm) was determined, as an indicator of photosynthetic performance. The data demonstrate that shallow-water species such as *P. palmata* are much less affected by natural photosynthetically active radiation (PAR) and UV radiation near the surface than extremely sensitive deep-water species such as *Phyc. rubens* which exhibited strong decreases in photosynthetic performance, as well as photobleaching of part of the thallus. The other species showed intermediate response patterns. In most species investigated inhibition of photosynthesis was mainly caused by the UV-B wavelengths. Interpretation of the data clearly indicates species-specific tolerances of photosynthesis to ambient solar radiation which can be explained by broad physiological acclimation potentials and/or genetic adaptation to certain (low or high) irradiances. The species-specific photosynthetic performance under radiation stress is in good accordance with the vertical distribution of the macroalgae on the shore.

Leinaas, H. P. and H. Christie. 1996. Effects of removing sea urchins (*Strongylocentrotus droebachiensis*): Stability of the barren state and succession of kelp forest recovery in the east Atlantic. *Oecologia* 105:524-536.

Author Abstract. Stability properties of the barren state of a kelp forest-sea urchin system were studied in northern Norway. The ability of the sea urchin *Strongylocentrotus droebachiensis* to maintain high population densities and recover from perturbations, and the succession of kelp forest revegetation, were studied experimentally by reducing the sea urchin density on a barren skerry. Additional information was obtained from community changes following a natural, but patchy, sea urchin mortality that varied between sites. On the barren grounds, high sea urchin densities (30-50 per m^2) are maintained by annual recruitment. Severe reductions of sea urchin densities initiated luxuriant kelp growth, while more moderate reductions allowed establishment of opportunistic algae (during spring and early summer), but no kelps. Succession of algal growth, after the severe decline in sea urchin densities, followed a predictable pattern. At first the substrate was colonized by filamentous algae, but within a few weeks they were outcompeted by the fast growing kelp *Laminaria saccharina.* After 3-4 years of the removal experiment, the slower-growing, long-lived kelp *L. hyperborea* became increasingly dominant. Increased food availability after reduction in sea urchin density led to increased individual growth of the remaining sea urchins. However, the population density did not increase, neither from recruitment nor immigration from adjacent areas with high sea urchin densities. Possibly, early establishment of a dense kelp stand, may represent a breakpoint in the ability of sea urchins to reestablish a barren state. The ability of *L. saccharina* quickly to invade and monopolize an area may have both positive and negative effects on the succession towards the climax *L.*

hyperborea kelp forest. Competitive interactions may slow the process, but development of a dense stand of *L. saccharina* will also reduce grazing risk on scattered recruits of the more slowly growing *L. hyperborea.*

Lindstrom, S. C., J. P. Houghton and D. C. Lees. 1999. Intertidal macroalgal community structure in southwestern Prince William Sound, Alaska. *Botanica Marina* 42:265-280.

Researchers conducted long-term sampling of the intertidal zone in southwestern Prince William Sound after the *Exxon Valdez* oil spill. From 1989-1996 samples were taken in twenty-one intertidal locations which include mixed soft substrata, small boulder cobble and three rocky bedrock types. Oiling and treatments used include: unoiled, oiled, and unwashed; and oiled and washed with warm or hot water. Mixed gravel/sand/silt (mixed-soft) sites were characterized by *Fucus gardneri,* bivalves (*Mytilus spp*) and barnacles (*Balanus spp*.) in the mid-intertidal and by *Cladophora sericea, Fucus,* and *Pilayella littoralis* in the low intertidal zone. *Polysiphonia aff. tongatensis* was found only at mixed-soft sites. Boulder-cobble sites were characterized by *Acrosiphonia arcta, Fucus gardneri,* and 'Ralfsia' sp. in the low zone; in the mid-zone vegetation is minimal. Methods for evaluating impacts included the use of a 30-m horizontal transect line at three elevations at most sites. Points were located randomly along each transect line for placement of five or ten quadrats. Sampling points were marked permanently to ensure that quadrats are situated precisely each year (0.50m X 0.50m). Photographs were taken of each quadrat per year. Species were identified in each quadrat and categorized. Benthic macroalgae presence was confirmed using non-quantitative synoptic collapses. Species abundance was used in data analyses. Data analysis was then manipulated and analyzed using Microsoft excel and Principal Components Analysis (PCA). Results showed significant changes in annual species abundance over time, and interannual differences in species abundance and richness. See publication for additional information on techniques used for evaluating and analyzing macroalgae abundance.

Lyngby, J. E., S. M. Mortensen and M. Munawar (eds.). 1994. Assessment of nutrient availability and limitation using macroalgae. *Journal of Aquatic and Ecosystem Health* 3: 27-34.

Author Abstract. Researchers used macroalga as indictors for nutrient availability that also limits macroalga density. Macroalga, *Ulva lactuca* L., were transplanted around an ocean outfall and at a reference site in Koge Bay, Denmark, to assess the influence of outfall on the nutrient availability. Ten discs of *Ulva lactuca* were transplanted to perforated plexiglass cages and incubated at depths 0.5m, 2m and 3.5m. Samples were collected and analyzed for growth, nitrogen, and phosphorus content at 2-week intervals. Total nitrogen and total phosphorous was analyzed using the procedure by researcher Nordforsh (1975). Nitrogen was measured using titrimetrically and phosphorous colometrically. ANOVA Duncan multiple range test was performed on data collected. Results showed that the nitrogen and phosphorus tissue concentrations decreased away from the outfall. This indicated that tissue concentrations are apt for monitoring nutrient availability in coastal areas. The lowest tissue concentrations of nitrogen were recorded at the reference station, where the internal concentrations generally were below the critical concentration level, showing that nitrogen limited the growth. At the station located close to the outfall, the flux of nitrogen was sufficient to maintain the maximum growth rate. The tissue concentrations of phosphorus were only below the critical concentration level on one occasion, and the result showed a net uptake throughout the study period. Researchers concluded that nitrogen was the primary limiting factor for macroalgae growth during the summer. The applicability of tissue concentrations for assessment of nutrient availability is discussed and it is considered that the method, when evaluated against established critical concentrations, provides a valuable tool for assessing ecosystem health with regard to eutrophication.

McAlary, F. A. and W. N. McFarland. 1994. Catalina Island kelp forests: 1992-1993, pp. 35-44. In Halvorson, W. L. and G. J. Maender (eds.), Fourth California Islands Symposium*:* Update on the Status of Resources. Santa Barbara Museum of Natural History, Santa Barbara, CA.

Author Abstract. A monitoring project initiated in the spring of 1992 at the Catalina Marine Life Refuge focused on Giant kelp (*Macrocystis pyrifera*), sea urchins *(Strongylocentrotus* and *Centrostephanus*), and water temperatures along 60-m longshore transects at depths of 4, 10, and 20 m. Quarterly assessment of plant size and density tracked a continuing decline in kelp abundance at the site coincident with elevated sea temperatures. Frond elongation fell precipitously through the summer of 1992 and reached a low in the winter of 1993. Growth remained depressed through the spring and summer of 1993. This contrasts with previously measured temporal patterns of growth at this site when rates were highest in winter and spring. Population densities of sea urchins were relatively constant. Diminishment of the kelp forest together with the appearance of pelagic red crabs, a juvenile green turtle, and several species of tropical fish at Catalina portrays effects of lingering worldwide "El Niño" conditions.

McAlary, F. A., T. W. Turney, and J .L. Turney. 2000. Catalina Island kelp forests: 1992 to 1998, pp. 363-369. In Brown, D. R., K. L. Mitchell and H. W. Chaney (eds.), Proceedings of the fifth California islands symposium. United States Department of the Interior, Minerals Management Service, Pacific OCS Region, Camarillo, CA.

Author Abstract. To assess long-term changes in kelp forests at Santa Catalina Island, the Catalina Conservancy Divers recorded benthic water temperatures and conducted quarterly censuses of Giant kelp (*Macrocystis pyrifera*) and sea urchins along three permanent 120 m^2 transects at 4-m, 10-m, and 20-m depths since 1992. Catastrophic declines of *Macrocystis* occurred in 1992 and 1997 El Niño events. Rates of frond elongation (RFE) correlated with fluctuations in plant biomass and population density, but not plant size, which emphasized recruitment in maintaining Giant kelp at this site. Within seasons, RFE were highest at the lowest mean temperatures and declined significantly with exposure to water above 18 degree C. Data suggest that thermal anomalies such as El Niño led to the reduction of Giant kelp by intensifying stressful conditions in summer (high temperatures, low nutrients) and, also, by limiting production during winter and spring. Overgrazing of kelp by sea urchins was not observed. Depth distributions for three species of sea urchins remained stable from 1992 to 1998. Densities of *Strongylocentrotus purpuratus* and *S. franciscanus* declined, especially in 1992 and 1993, with the disappearance of Giant kelp and signs of echinoderm wasting disease. Increases in the density of *Centrostephanus coronatus*, a species with tropical affinities, exemplify the potential shift toward warm water species.

McClanahan, T. R., M. McField, M. Huitric, K. Bergman, E. Sala, M. Nystroem, I. Nordemar, T. Elfwing and N. A. Muthiga. 2001. Responses of algae, corals and fish to

the reduction of macroalgae in fished and unfished patch reefs of Glovers Reef Atoll, Belize. *Coral Reefs* 19:367-379.

Author Abstract. Macroalgae were experimentally reduced by approximately 2.5 kg/m^{-2} on eight similar-sized patch reefs of Glovers Reef Atoll, Belize, in September 1998. Four of these reefs were in a protected "no-take" zone and four were in "general use" fishing zone. Eight adjacent reefs (four in each management zone) were also studied as unmanipulated controls to determine the interactive effect of algal reduction and fisheries management on algae, coral, fish, and rates of herbivory. The 16 reefs were sampled five times for 1 year after the manipulation. We found that the no-fishing zone had greater population densities for 13 of 30 species of fish, including four herbivorous species, but lower herbivory levels by sea urchins. However, there was lower stony coral cover and higher macroalgal cover in the "no-take" zone, both prior to and after the experiment. There were no significant effects of management on the percent cover of fleshy macroalgae. The algal reduction resulted in an increase in six fish species, including four herbivores and two which feed on invertebrates. One species, *Lutjanus griseus*, declined in experimental reefs. Macroalgal biomass quickly recovered from the reduction in both management areas within a few months, and by species-level community measures within 1 year, while stony coral was reduced in all treatments. Coral bleaching and Hurricane Mitch disturbed the site at the beginning of the study period and may explain the loss of stony coral and rapid increase in erect algae. We suggest that reducing macroalgae, as a technique to restore turf and encrusting coralline algae and stony corals, may work best after reefs have been fully protected from fishing for a period long enough to allow herbivorous fish to recover (i.e., > 5 years). Further ecological studies on Glovers Reef are required to understand the shift from coral to algal dominance that has occurred on this reef in the last 25 years.

Mearns, A., G. Watabayashi and J. Lankford. 2001. Dispersing oil near shore in the California current region. *Reports of California Cooperative Oceanic Fisheries Investigations* 42:97-109.

Author Abstract. Mathematical models were used to develop scenarios for evaluating alternative nearshore responses to oil spills, including the use of chemical dispersants. The scenarios were used in ecological risk assessment (ERA) workshops designed to help fisheries, wildlife, and resource managers determine whether they would support pre-approving the use of dispersants. Resource managers proposed a worst-case spill scenario for the Gulf of the Farallones. Models were used to compare five options—no response, mechanical, burning, and two levels of dispersants--showing the trajectories, fate, and concentration of oil in surface slicks and dispersed oil plumes. Participating biologists used current data on dispersant and dispersed oil toxicity to develop consensus-based toxicity guidelines. During the first several hours following dispersal, the simulated dispersed oil concentrations exceeded guidelines for early life-history stages of fishes and zooplankton; adult fish and crustaceans were at risk for two hours. The benefits and risks to fishes, seabirds, cetaceans, pinnipeds, sea otters, and shoreline resources (marshes, kelp beds, and protected areas) were compared for the five response options. Dispersants substantially reduced the amount of both floating and stranded oil relative to the other options. Furthermore, the higher dispersant level (85%) removed more oil than the lower level (35%). Risk assessments so far indicate that chemical dispersion can reduce the overall ecological effects of a nearshore oil spill. The final decision to pre-approve dispersant use along the Pacific Coast will still require input from the political, social, and economic sectors.

Moore, P. G. 1973. The kelp fauna of northeast Britain 1.: Introduction and the physical environment. *Journal of Experimental Marine Biology and Ecology* 13:97-125.

Author Abstract. As part of a multidisciplinary investigation of pollution in northeast Britain a study of the sublittoral kelp fauna is described. Sampling strategy is discussed and a program adopted involving the investigation of an instantaneous faunal pattern over a wide area and its environmental correlation. The kelp holdfast (thallus) as a sample unit is briefly evaluated. The total faunal content of the survey samples is described in gross terms. A review of the physical parameters which impinge upon the holdfast fauna is made and on this basis significant variables are resolved into turbidity, pollution, water movement, and holdfast morphology. Detailed treatment of these factors follows and their distribution over the northeast coast transect is described. Seasonal studies on suspended solids enable an approximate area north of the River Coquet in Northumberland to be considered as continually clear, whilst the area to the south is considered turbid. The region of turbid water is considered to be the consequence of erosion of superficial coastal deposits under the action of marine and atmospheric forces. The role of discharges in contributing to suspended solids is considered. Nutrient data are given; the amounts were spatially similar over the whole coastline. An area of 'pollution' is provisionally designated on the basis of published figures. The problems of assessment of wave exposure and present inadequate knowledge of local inshore current systems preclude other than crude separation of one site on considerations of water movement. Holdfast parameters are generally interdependent: however, the degree of holdfast branching is shown to be independent of age and to influence significantly (along with water movement external to the holdfast) the degree of holdfast silting.

Reed, D. C. and M. S. Foster. 1984. The effects of canopy shading on algal recruitment and growth in a giant kelp forest. *Ecology* 65: 937-948.

Author Abstract. The subtidal assemblage in the relatively sheltered giant kelp forest at Stillwater Cove in Carmel Bay, California, consists of perennial species forming three major vertical layers: a *Macrocytis purifera* surface canopy, a dense subsurface canopy of another kelp (*Pterygophora californica)* and an understory of articulated and encrusting coralline algae. The effects of light reduction by these vegetation layers on algal recruitment and subsequent growth were determined by removing various combinations of canopies over a 2-yr period, and following subsequent changes relative to appropriate controls. Removing both *M. pyrifera* and *P. californica* canopies resulted in moderate recruitment of these species as well as of the annual brown alga *Desmarestia ligulata* var. Relatively low levels of both physical and biological disturbance in Stillwater Cove allow the establishment of a few perennial algal species that inhibit their own recruitment, as well as invasion of other species, by shading.

Simms, E. L. and J. M. M. Dubois. 2001. Satellite remote sensing of submerged kelp beds on the Atlantic coast of Canada. *International Journal of Remote Sensing* 22:2083-2094.

Author Abstract. Underwater kelp seasonal variation is assessed through the comparative analysis of HRV and Thematic Mapper (TM) images of Baie des Chaleurs between Caps-Noirs and Pointe-Bonaventure, Quebec. The total biomass is estimated, based on the morphology of the dominant species *Laminaria longicruris*. Kelp-covered and kelp-free areas are differentiated from each other in water depth of 0-6 m and 0-7 m with the HRV and TM images, respectively. The median biomass estimated for the kelp-covered category of the classified image is (1500 ± 400) g/m^{-2}. The multidate image shows a spatial variation of the kelp beds in 45% of the area. Areas where no change occurred occupy at least 70 ha, while growth and decay of kelp are observed in much smaller areas, in shallow water and at the boundary of kelp beds.

Singer, M. M., R. S. Tjeerdema and R. S. Smalheer. 1992. Evaluation of the toxicological effects of oil dispersants by modeled-exposure toxicity testing, pp. 175-182. In Niimi, A. J. and M. C. Taylor (eds.), Proceedings of the Eighteenth Annual Toxicity Workshop: September 30 – October 3, 1991, Ottawa, Ontario. Canadian Technical Report on Fish Aquatic Sciences 1863.

Author Abstract. By virtue of their nature and usage, the exposure potential of aquatic organisms to oil dispersants is highly ephemeral. To address this circumstance, in addition to traditional constant-concentration exposures, more realistic spiked-exposure, continuous-flow toxicity tests using the oil dispersant Corexit 9527 were performed using the early life stages of four California marine species: the Giant kelp (*Macrocystis pyrifera),* the red abalone (*Haliotis rufescens*), a kelp forest mysid (*Holmesimysis costata*), and the topsmelt (*Atherinops affinis*), were inoculated with concentrated dispersant, then allowed to flush with clean, filtered seawater. Spectrophotometric monitoring of tests showed dispersant levels diminishing to below detection limits within 5 to 6 h or less. Comparison of spiked-exposure results with previous data obtained using the same species and dispersant under constant-exposure conditions showed higher values for both EC/LC50s and NOECs under spiked conditions.

Stekoll M. S. and L. Deysher. 1996. Recolonization and restoration of upper intertidal *Fucus gardneri* (Fucales, Phaeophyta) following the *Exxon Valdez* oil spill. *Hydrobiologia* 327:311-316.

Author Abstract. The *Exxon Valdez* oil spill in March 1989 and subsequent cleanup caused injury to intertidal *Fucus gardneri* populations especially in the upper intertidal. A survey in 1994 in Prince William Sound, Alaska showed that the upper boundary of *Fucus* populations at oiled sites was still an average of 0.4 m lower than the upper boundary at unoiled sites. Restoration of severely damaged *Fucus* populations was started on a small-scale at a heavily oiled rocky site in Herring Bay, Prince William Sound. Experiments employed mats of biodegradable erosion control fabric to act as a substratum for *Fucus* germlings and to protect germlings from heat and desiccation stress. A series of plots was covered with mats made from a resilient coconut-fiber fabric in June 1993. Half of the mats were inoculated with *Fucus* zygotes. A series of uncovered control plots was also monitored. There was no enhancement of Fucus recruitment on the rock surfaces under the mats. Dense populations of *Fucus* developed on the surface of all of the mats by the summer of 1994. The natural rock surfaces in the control plots, both inoculated and not, were barren of macroscopic algal cover. By September 1994, the juvenile thalli on the mats were approximately 2 cm in length. Inoculating the mats had an effect only in the upper region of the intertidal. It is expected that the thalli will become fertile during the 1995 season. These thalli may serve as a source of embryos to enhance the recovery of new *Fucus* populations in this high intertidal area.

Steneck, R. S. and M. N. Dethier. 1994. A functional group approach to the structure of algal-dominated communities. *Oikos* 69: 476-498.

Author Abstract. We suggest that relatively few species attributes are of overriding importance to the structure of benthic marine algal communities and that these are often shared among taxonomically distant species. Data from the western North Atlantic, eastern North Pacific and Caribbean suggest that patterns in algal biomass, diversity and dominance are strikingly convergent when examined at a functional group level relative to the productivity and herbivore-induced disturbance potentials of the environment. We present a simple graphical model that provides a way to predict algal community composition based on these two environmental axes. This predictability stems from algal functional groups having characteristic rates of mass-specific productivity, thallus longevity and canopy height that cause them to "behave" in similar ways. Further, herbivore-induced disturbances have functionally similar impacts on most morphologically and anatomically similar algae regardless of their taxonomic or geographic affinities. Strategies identified for marine algae parallel those of a terrestrial scheme with the addition of disturbance-tolerant plants that characteristically coexist with and even thrive under high levels of disturbance. Algal-dominated communities, when examined at the functional group level, appear to be much more temporally stable and predictable than when examined at the species level.

Tegner, M. J., P. L. Haaker, K. L. Riser and L. I. Vilchis. 2001. Climate variability, kelp forests, and the southern California red abalone fishery. *Journal of Shellfish Research* 20:755-763.

Author Abstract. Declines in landings of Southern California abalone fisheries and the eventual collapse of many stocks over the last two decades coincided with a period of greatly increased environmental variability. This included massive storms, an increase in the frequency of warm-water El Niño events after 1976, and an interdecadal-scale increase in sea surface temperatures. Kelp populations may be decimated by severe storms or warm water. Because of the strong inverse relationship between nitrate availability and water temperature, temperature is a good indicator of nitrate availability or stress since kelp growth ceases in warm nutrient-depleted water, tissue decays, and standing stocks may be greatly reduced. Abalones are affected by the availability of the drift kelp on which they feed. Anomalously warm temperatures may affect reproduction, and altered current patterns may affect larval dispersal. Because water temperature varies with location in southern California and each of the five exploited abalone species has its own thermal preferences, we chose to evaluate the role of environmental variability on populations of red abalone (*Haliotis rufescens*) on three northern Channel Islands spanning a temperature gradient. We compared water temperature regimes and anomalies, monthly aerial surveys of canopies of Giant kelp (*Macrocystis pyrifera*), and field evidence of poor abalone growth and reproduction during El Niño events. The severity of El Niño disturbances and long-term changes in kelp standing stocks both correlated with the temperature gradient. Declines of red abalone total landings and area-specific landings on the warmer Santa Cruz and Santa Rosa Island began a decade after the large 1957-1959 El Niño. The subsequent collapse of many populations appears related to warm anomalies after the 1976-1977 regime shift, kelp declines, and poor reproduction coupled with fishing-induced declines in adult abalone density. Red abalone populations have persisted on cooler San Miguel Island where thermal anomalies had less effect and kelp canopy biomass has been more stable. Southern California abalones evolved in this disturbance regime, but the combination of extended periods of increased environmental variability with intense fishing pressure may have led to the loss of local populations, especially in warmer areas.

Terawaki, T. and H. Goto. 1988. Preliminary study for creation of kelp forest, (Part 1).

Seasonal Changes of Lamina and Growth of Root of *Elsenia bicyclis* in Odawa Bay, Miura Peninsula, 24 p. Central Research Institute of Electric Power Industry (CRIE-U-87056), Tokyo, Japan.

Author Abstract. A preliminary study for the creation of a kelp forest has been carried out in Odawa Bay, Kanagawa Prefecture. In foreshore reclamation on an electric power plant siting, the restoration and substitution measures of kelp forest are important for the protection of living aquatic resources and marine environment. Observations on seasonal changes of lamina and growth of root of *Eisenia bicyclis* were carried out during July 1984 to October 1985. The maximum weight of a lamina reached about 600g during July to August, then decreased and reached a minimum weight of 120g in November. The maturation period was observed from September to March. Primary pinnae length reached maximum of 57cm a March to April and a minimum of 30cm in October. Its width reached a maximum of 9cm in July and the minimum of 6cm in November. New root growth occurred in October, reached rockbed exceeded old root growth by April. New root weight occupied 40% of the whole holdfast weight. The period from November to February, when maturation and root growth are active, is an important season for the preservation of the *E. bicyclis* population, and is suitable for seeding and transplanting.

Vasquez, J. A. and R. H. McPeak. 1998. A new tool for kelp restoration**.** *California Fish and Game* 84:149-158.

Researchers developed new techniques for restoring and protecting Giant kelp, *Macrocystis pyrifera*, forests in southern California. These techniques include the use of artificial kelp plants that are constructed of plastic. The blades of these artificial plants would sweep across the substrate similar to that reported in natural kelp populations in Chile and southern California. This sweeping movement helps with filtering of sediments, functioning of the ecosystem along with other functions. Based on results the artificial plants reduced purple sea urchins density, *Strongylocentrotus purpuratus*, by about 85% and red sea urchins, *S. franciscanu*s, by 75% in sea-urchin-dominated areas. The artificial plants successfully protected Giant kelp transplants that were present in sea-urchin-dominated areas. See publication for additional information on kelp restoration techniques.

Wilson, K. C. and W. J. North. 1983. A review of kelp bed management in southern California. *Journal of World Mariculture Society* 14: 347-359.

Author Abstract. Methods for maintaining and enhancing stands of Giant kelp (*Macrocystis spp*.) continue to evolve. This paper reviews the history of kelp management techniques and describes recent research, as well as new methodology that have come into general usage. The southern California kelp populations are basically wild crops, but survival and biomass production can be significantly affected by relatively moderate inputs of human effort. Methodologies discussed include urchin control techniques (hammering, suction dredging, quick-lime, and harvesting urchins as specialty foods), culturing and transplanting kelp, control of competitive weeds, and monitoring. New research areas include improved understanding of the kelp ecosystem, kelp nutrition (with possibilities for enhancing productivity by fertilizing), genetics and breeding, optimizing biomass density, and expanding beds by use of artificial substrates.

APPENDIX II: KELP AND OTHER MACROALGAE
REVIEW OF TECHNICAL METHODS MANUALS

This Review of Technical Methods Manuals includes a variety of sampling manuals, Quality Assurance/Quality Control (QA/QC) documents, standardized protocols, or other technical resources that may provide practitioners with the level of detail needed when developing a monitoring plan for a coastal restoration project. Examples from both peer reviewed and grey literature are presented. Entries were selected through extensive literature and Internet searches as well as input from reviewers. As with the Annotated Bibliographies, these entries are not, however, a complete list. Entries are arranged alphabetically by author. Wherever possible, web addresses or other contact information is included in the reference to assist readers in easily obtaining the original resource. Summaries preceded by the terms '*Author Abstract'* or *'Publisher Introduction*' or similar descriptors were taken directly from their original source. Summaries without such descriptors were written by the authors of the associated chapters.

Bushing, W. W. 2000. Monitoring the persistence of giant kelp around Santa Catalina island using a geographic information system. *Journal of Phycology* 36: 9-10.

Author Abstract. Geographic information systems (GIS) facilitate monitoring and analysis of population distributions at spatial and temporal scales differing from those employed in conventional field monitoring. This study utilizes a GIS-based gap analysis of a network of marine reserves around Santa Catalina Island relative to the regional ecology, disturbance regime, and persistence of giant kelp (*Macrocystis pyrifera*), a keystone species in the nearshore, marine environment. Catalina's orientation and greatly-dissected coastline create diverse microhabitats with respect to storm exposure, temperature, light regime and topographic factors. GIS overlay methods applied to multi-temporal kelp distribution maps generated a model representing the spatial "persistence" of kelp. Correlations between the kelp's geographic distribution and persistence, the disturbance regime and physical variables conferring resistance to or recovery from it were drawn. This analysis identified regions of persistent kelp under disturbance regimes markedly different from those in the existing reserves, suggesting the designation of additional reserves in unprotected areas is ecologically warranted.

Davies, J., J. Baxter, M. Bradley, D. Connor, J. Khan, E. Murray, W. Sanderson, C. Turnbull and M. Vincent. 2001. Marine Monitoring Handbook. UK Marine Science Project, and Scottish Association of Marine Science. Joint Nature conservation Committee, English Nature, Scottish Natural Heritage, Environment and Heritage Services. http://www.jncc.gov.uk/marine/mmh/Introduction.pdf.

The UK Marine Science Project developed this hand book to provide guidelines for recording, monitoring and reporting characteristics and conditions of marine habitats. However, based on location and other environmental conditions methodologies will have to be modified to suit the structural characteristics of the habitat. This manual addresses the fundamentals and procedures for monitoring different parameters in marine habitats, management tools, and benefits and costs for developing a monitoring project. Topics presented in this document include establishing marine monitoring programs highlighting what needs to be measured and methods to use; provides guidance when developing a monitoring program; selecting proper monitoring techniques to attain precision and accuracy; and procedural guidelines for monitoring a specific marine habitat. Detailed information on the tools needed for monitoring marine habitats are described within the marine monitoring handbook.

Davis, G. E., K. R. Faulkner and W. L. Halvorson. 1994. Ecological monitoring in Channel Islands National Park, California, pp. 465-482. In Halvorson, W. L. and G. J. Maender (eds.), The 4th California Islands Symposium: Update on the Status of Resources.

Author Abstract. Natural resource managers need to understand the natural functioning of and threats to ecosystems under their management. They need a long-term monitoring program to gather information on ecosystem health, establish empirical limits of variation, diagnose abnormal conditions, and identify potential agents of change. The approach used to design such a program at Channel Islands National Park, California, may be applied to other ecosystems worldwide. The design of the monitoring program began with a conceptual model of the park ecosystem. Indicator species from each ecosystem component were selected using a Delphi approach. Scientists identified parameters of population dynamics to measure, such as abundance, distribution, age structure, reproductive effort, and growth rate. Short-term design studies were conducted to develop monitoring protocols for pinnipeds, seabirds, rocky intertidal communities, kelp forest communities, terrestrial vertebrates, land birds, terrestrial vegetation, fishery harvest, visitors, weather, sand beach and coastal lagoon, and terrestrial invertebrates (indicated in priority order set by park staff). Monitoring information provides park and natural resource managers with useful products for planning, program evaluation, and critical issue identification. It also provides the scientific community with an ecosystem-wide framework of population information.

Deysher, L. E. 1993. Evaluation of remote sensing techniques for monitoring giant kelp populations. *Hydrobiologia* 260-261:307-312.

Author Abstract. Photographs and maps of the floating canopy of the giant kelp, *Macrocystis pyrifera*, provide an important data source to monitor nearshore water quality in southern California. Declines in water quality related to turbidity from coastal development, ocean discharges, and non-point source runoff have caused reductions in the areal extent of these kelp beds. Historically the kelp beds have been monitored by a variety of methods including small format infrared and color photography. New digital remote sensing instruments combined with geographical information system (GIS) databases offer an efficient method for collecting and analyzing data on changes in kelp bed size and location. SPOT satellite imagery has been found to provide adequate resolution for mapping the larger beds of giant kelp along the California coast. Beds smaller than 10 ha are not resolved well with SPOT imagery and need to be mapped with a resolution greater than the 20 m pixel size provided by the SPOT multispectral imagery. Imagery from a prototype of the Positive Systems ADAR system, an airplane mounted multispectral video sensor, provided a spatial resolution of 2.3 m in 4 spectral bands. ADAR imagery taken on 2 October 1991 of the San Onofre Kelp Bed in northern San Diego County showed 39% more kelp than small format color infrared photography made during the same time period.

Halse, S. A., D. J. Cale, E. J. Jasinska and R. J. Shiel. 2002. Monitoring change in aquatic invertebrate biodiversity: sample size, faunal elements and analytical methods. *Aquatic Ecology* 36:395-410.

Author Abstract. Replication is usually regarded as an integral part of biological sampling, yet the cost of extensive within-wetland replication prohibits its use in broad-scale monitoring of trends in aquatic invertebrate biodiversity. In this paper, we report results of testing an alternative protocol, whereby only two samples are collected from a wetland per monitoring event and then analyzed using ordination to detect any changes in invertebrate biodiversity over time. Simulated data suggested ordination of combined data from the two samples would detect 20% species turnover and be a cost-effective method of monitoring changes in biodiversity, whereas power analyses showed about 10 samples were required to detect 20% change in species richness using ANOVA. Errors will be higher if years with extreme climatic events (e.g., drought), which often have dramatic short-term effects on invertebrate communities, are included in analyses. We also suggest that protocols for monitoring aquatic invertebrate biodiversity should include microinvertebrates. Almost half the species collected from the wetlands in this study were microinvertebrates and their biodiversity was poorly predicted by macroinvertebrate data.

McCobb, T. D. and P. K. Wieskel. 2003. Long-Term Hydrologic Monitoring Protocol for Coastal Ecosystems, 94 pp. United States Geological Survey Open-File Report 02-497. http://water.usgs.gov/pubs/of/2002/ofr02497/

The United States Geological Survey (USGS) and the National Park Service have designed and tested monitoring protocols implemented at Cape Cod National Seashore. The monitoring protocols are divided into two parts. Part one of the protocol discusses the objectives of the monitoring protocol and presents rationale for the recommended sampling program. The second part describes the field, data-analysis, and data-management, and variables that are to be taken into consideration when monitoring (e.g., sea level rise, climate change and urbanization). This protocol provides consistency when monitoring changes in ground-water levels, pond levels, and stream discharge. The monitoring protocol not only establishes a hydrologic sampling network but provides reasoning for measurement methods selected and spatial and temporal sampling frequency. Data collected during the first year of monitoring and hydrologic analyses for selected sites are presented. Long-term hydrologic monitoring procedures performed at the Cape Cod National Seashore may also assist set a template for deciphering findings of other monitoring programs.

Oregon Watershed Enhancement Board. 1999. Oregon Aquatic Habitat: Restoration and Enhancement Guide. Contact information: 775 Summer street, suite 360, Salem Oregon, 97301, Phone# (503) 986-0178. http://www.oweb.state.or.us/publications/habguide99.shtml

This guide was developed to provide guidance on restoration and enhancement measures that would assist in aquatic ecosystem recovery. The guide is divided into five sections: An overview of restoration activities, activity guidelines, overview of agency regulatory functions and sources of assistance, grants and assistance, and monitoring and reporting. The purpose of this document is to provide information that will assist in developing effective restoration projects; to define standards and priorities that will be approve by state and receive funding or authorized restoration projects; to identify state and federal regulatory requirements and receive assistance in restoration projects. Additional information on monitoring techniques for salmonid restoration and guidelines and considerations for reporting restoration progress over time are described within the document.

Reed, B., C. Collier, J. Altstatt, N. Caruso and K. Lewand. 2002. Regional Kelp Restoration Project: Restoration and Monitoring

Protocol. California CoastKeeper Alliance, Kelp Restoration Team, Santa Monica, CA.

The California CoastKeeper Alliance (CCKA) presents restoration techniques that are used in kelp habitats. Described in this document are protocols for kelp restoration and kelp monitoring. Methods used for kelp restoration include: outplanting of kelp in which kelp sporophytes are cultivated in the laboratory, transplanting of the drift kelp, sporophyll bags and how grazers are removed (e.g., sea urchins). The Coastal Resource Associates in Carlsbad stated however that outplanting of juvenile kelp seems the most cost effective for restoration work. Methods described in the kelp monitoring protocol include: quadrats, band transects, roving diver fish survey, sea urchin size frequency survey, Giant kelp plant tagging survey, substrate survey and temperature monitoring. Detailed information on methods used for restoration and monitoring are described in the document.

Trippel, E. A. 2001. Marine Biodiversity Monitoring: Protocol for Monitoring of Fish Communities. A Report by the Marine Biodiversity Monitoring Committee (Atlantic Maritime Ecological Science Cooperative, Huntsman Marine Science Centre) to the Ecological Monitoring and Assessment Network of Environment Canada. http://www.eman-rese.ca/eman/ecotools/protocols/marine/fishes/intro.html#Rationale

This document presents a monitoring protocol for estimating species diversity of bottom dwelling or demersal fish species inhabiting the Canadian continental shelf regions. Monitoring protocols presented in this document can be used to monitor and evaluate fish communities in regions other than the Canadian continental shelf. Methods used to estimate the abundance of different demersal fish species include random stratified sampling and fixed station sampling. Using these standardized procedures helps to maintain precision. Some factors taken into consideration when monitoring fish communities include depth, temperature, salinity, seasonal shifts and diurnal behavior patterns. Additional information found in this document includes size of area and sampling intensity, sampling gear, sampling procedures, and treatment of data.

United States Environmental Protection Agency (USEPA). 1992. Monitoring Guidance for the National Estuary Program. United States Environmental Protection Agency, Office of Water, Office of Wetlands, Washington D.C. EPA Report 842-B-92-004.

This document provides guidance on the design, implementation, and evaluation of the required monitoring programs. It also identifies steps to be taken when developing and implementing estuarine monitoring programs and provides a technical basis for discussions on the development of monitoring program objectives, the selection of monitoring program components, and the allocation of sampling effort.

Some of the criteria listed for developing a monitoring program and described in this document include: monitoring program objectives, performance criteria, establish testable hypotheses, selection of statistical methods, alternative sampling designs, use of existing monitoring programs, and evaluate monitoring program performance. Additional information on guidelines for developing a monitoring program is described in this document.

United States Environmental Protection Agency (USEPA). 1993. Volunteer Estuary Monitoring, 176 pp. In Ohrel, R. L. Jr. and

K. M. Register (eds.), A Methods Manual. U.S. Environmental Protection Agency, Washington, D.C., Office of Water. EPA Report- 842-B-93-004. http://www.epa.gov/owow/estuaries/monitor/.

This document presents information and methods specific to measuring estuarine water quality. Information presented in the first eight chapters includes: understanding estuaries and what makes them unique, impacts to estuarine habitats and society's role in solving the problems; guidance on how to establish and maintain a volunteer monitoring program; guidance for working with volunteers and ensuring that they are well-positioned to collect water quality data safely and effectively; ensuring that the program consistently produces high quality data; and guidenace for managing the data and making it readily available to data users. Also presented are water quality measures that determine the condition of the estuary. These include physical (e.g., substrate texture), chemical (e.g., dissolved oxygen), and biological parameters (e.g., plant and animal presence and abundance). The importance of each parameter and methods used to monitor the conditions are described in a gradual process. Proper quality assurance and quality control techniques must also be described in detail to ensure that the data are beneficial to state agencies and other data users.

Wenner, E. L. and M. Geist. 2001. The national estuarine research reserves program to monitor and preserve estuarine waters. *Coastal Management* 29:1-17.

The National Estuarine Research Reserve (NERR) sites in 1992 coordinated a program that would attempt to identify and track short-term variability and long-term changes in representative estuarine ecosystems and coastal watersheds. Water quality parameters that were monitored include: pH, conductivity, temperature, dissolved oxygen, turbidity, and water level. Standardized protocols were also used at each site so that sampling, processing, and data management techniques were consistent among sites. Statistical techniques are being used to identify periodicity in water quality variables. Periodic regression analysis indicated that diel periodicity in dissolved oxygen is a larger source of variation than tidal periodicity at sites with less tidal amplitude. Authors of this document stress how understanding the functions of estuaries and how they change over time will help predict how these systems respond to change in climate and anthropogenic sources.

APPENDIX III: LIST OF KELP AND OTHER MACROALGAE EXPERTS

The expert listed below has provided his contact information so practitioners may contact him with questions pertaining to the restoration or restoration monitoring of this habitat. Contact information is up-to-date as of the printing of this volume. The list below includes only those experts who were 1) contacted by the authors and 2) agreed to submit their contact information. In addition to this resource, practitioners are encouraged to seek out the advice of local experts as well faculty members and researchers at colleges and universities. Engineering, planning, and landscape architecture firms also have experts on staff or contract out the services of botanists, biologists, ecologists, and other experts whose skills are needed in restoration monitoring. These people are in the business of providing assistance in restoration and restoration monitoring and are often extremely knowledgeable in local habitats and how to implement projects on the ground. Finally local, state, and Federal environmental agencies also house many experts who monitor and manage coastal habitats. In addition to the National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), the Army Corps of Engineers (ACE), Fish and Wildlife Service (FWS), and the United States Geologic Survey (USGS) are important Federal agencies to contact for assistance in designing restoration and monitoring projects as well as potential sources of funding and permits to conduct work in coastal waterways.

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GLOSSARY

Abiotic - non-living

Adaptive management - a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form–"active" adaptive management–employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed.

Aerobic - (of an organism or tissue) requiring air for life; pertaining to or caused by the presence of oxygen

Algae - simple plants that are very small and live in water through photosynthesis, algae are the main producers of food and oxygen in water environments

Allochthanous - carbon that is formed outside of a particular area as opposed to an autochthanous carbon that is produced within a given area

Alluvial plain - the floodplain of a river, where the soils are alluvial deposits carried in by overflowing river

Alluvium - any sediment deposited by flowing water, as in a riverbed, floodplain, or delta

Alternate hypothesis - a statement about the values of one or more parameters usually describing a potential change

Anaerobic - living in the absence of air or free oxygen; pertaining to or caused by the absence of oxygen

Anoxic - without oxygen

Anthropogenic - caused by humans; often used when referring to human induced environmental degradation

Apical - the tips of the plants

Aquatic - living or growing in or on water

Asset mapping - a community assessment research method that provide a graphical representation of a community's capacities and assets

Assigned values - the relative importance or worth of something, usually in economic terms. Natural resource examples include the value of water for irrigation or hydropower, land for development, or forests for timber supply (see held values).

Attitude - an individual's consistent tendency to respond favorably or unfavorably toward a given attitude object. Attitudes can be canvassed through survey research and are often defined utilizing scales ranging from positive to negative evaluations.

Backwater - a body of water in which the flow is slowed or turned back by an obstruction such as a bridge or dam, an opposing current, or the movement of the tide

Baseline measurements - a set of measurements taken to assess the current or pre-restoration condition of a community or ecosystem

Basin morphology - the shape of the earth in the area a coastal habitat is found

Benefit-cost analysis - a comparison of economic benefits and costs to society of a policy, program, or action

Benthic - on the bottom or near the bottom of streams, lakes, or oceans

Bequest value - the value that people place on knowing that future generations will have the option to enjoy something

Biogenic - produced by living organisms

Biomass - the amount of living matter, in the form of organisms, present in a particular habitat, usually expressed as weight- per-unit area

Blackwater streams - streams that do not carry sediment, are tannic in nature and flow through peat-based areas

Brackish - water with a salinity intermediate between seawater and freshwater (containing from 1,000 to 10,000 milligrams per liter of dissolved solids)

Calcareous - sediment/soil formed of calcium carbonate or magnesium carbonate due to biological deposition or inorganic precipitation

Canopy formers - plants that form a diverse vertical habitat structure

Carnivores - organisms that feed on animals

Catchment - the land area drained by a river or stream; also known as "watershed" or "drainage basin"; the area is determined by topography that divides drainages between watersheds

Causality - or causation, refers to the relationship between causes and effects: i.e., to what extent does event 'A' (the cause) bring about effect 'B'

Coastal habitat restoration - the process of reestablishing a self-sustaining habitat in coastal areas that in time can come to closely resemble a natural condition in terms of structure and function

Coastal habitat restoration monitoring - the systematic collection and analysis of data that provides information useful for measuring coastal habitat restoration project performance

Cognitive mapping - a community assessment research method used to collect qualitative data and gain insight into how community members perceive their community and surrounding natural environment

Cohort studies - longitudinal research aimed at studying changing in a particular subpopulation or cohort (e.g., age group) over time (see longitudinal studies)

Community - all the groups of organisms living together in the same area, usually interacting or depending on each other for existence; all the living organisms present in an ecosystem

Community (human) - a group of people who interact socially, have common historical or other ties, meet each other's needs, share similar values, and often share physical space; A sense of "place" shaped by either natural boundaries (e.g., watershed), political or administrative boundaries (e.g., city, neighborhood), or physical infrastructure

Computer-assisted telephone interviewing (CATI) - a system for conducting telephone survey interviews that allows interviewers to enter data directly into a computer database. Some CATI systems also generate phone numbers and dial them automatically.

Concept mapping - community assessment research method that collects data about how community members perceive the causes or related factors of particular issues, topics, and problems

Content validity - in social science research content validity refers to the extent to which a measurement (i.e., performance standard) reflects the specific intended domain of content (i.e., stated goal or objective). That is, how well does the performance standard measure whether or not a particular project goal has been met?

Contingent choice method - estimates economic values for an ecosystem or environmental service. Based on individual's tradeoffs among sets of ecosystems, environmental services or characteristics. Does not directly ask for willingness to pay; inferred from tradeoffs that include cost as an attribute.

Contingent valuation method (CVM) - used when trying to determine an individual or individuals' monetary valuation of a resource. The CVM can be used to determine changes in resource value as related to an increase or decrease in resource quantity or quality. Used to measure non-use attributes such as existence and bequest values; market data is not used.

Coral reefs - highly diverse ecosystems, found in warm, clear, shallow waters of tropical oceans worldwide. They are composed of marine polyps that secrete a hard calcium carbonate skeleton, which serves as a base or substrate for the colony.

Coralline algae - algae that contains a coral-like, calcareous outer covering

Cost estimate - estimates on costs of planning and carrying out a project. Examples of items that may be included in a cost estimate for a monitoring plan may be personnel, authority to provide easements and rights-of-way, maintenance, labor, and equipment.

Coulter counter - a device that measures the amount of particles in water

Coverage error - a type of survey error that can occur when the list – or frame – from which a sample is drawn does not include all elements of the population that researchers wish to study

Cross-sectional studies - studies that investigate some phenomenon by taking a cross section (i.e., snapshot) of it at one time and analyzing that cross section carefully (see longitudinal studies)

Crowding - in outdoor recreation, crowding is a form of conflict (see outdoor recreation conflict) that is based on an individual's judgment of what is appropriate in a particular recreation activity and setting. Use level is not interpreted negatively as crowding until it is perceived to interfere with one's objectives or values. Besides use level, factors that can influence perceptions of crowding include participant's motivations, expectations, and experience related to the activity, and characteristics of those encountered such as group size, behavior, and mode of travel.

Cryptofauna - tiny invertebrates that hide in crevices

Cultch - empty oyster shells and other materials that are on the ground and used as a place of attachment

Culture - a system of learned behaviors, values, ideologies, and social arrangements. These features, in addition to tools and expressive elements such as graphic arts, help humans interpret their universe as well as deal with features of their environments, natural and social.

Cyanobacteria - blue-green pigmented bacteria; formerly called blue-green algae

Dataloggers - an electronic device that continually records data over time

Deepwater swamps - forested wetlands that develop along edges of lakes, alluvial river swamps, in slow-flowing strands, and in large, coastal-wetland complexes. They can be found along the Atlantic and Gulf Coasts and throughout the Mississippi River valley. They are distinguished from other forested habitats by the tolerance of the dominant vegetation to prolonged flooding.

Demersal - bottom-feeding or bottom-dwelling fish, crustaceans, and other free moving organisms

Detritivorous - the practice of eating primarily detritus

Detritus - fine particles of decaying organic and inorganic matter fomed by excrement and by plant and animal remains; maybe suspended in water or accumulated on the bottom of a water body

Diatoms - any of a class (Bacillariophyceae) of minute planktonic unicellular or colonial algae with silicified skeletons that form shells.

Direct impacts - the changes in economic activity during the first round of spending. For tourism this involves the impacts on the tourism industries (businesses selling directly to tourists) themselves (see Secondary Effects)

Dissolved oxygen - oxygen dissolved in water and available to aquatic organisms; one of the most important indicators of the condition of a water body; concentrations below 5 mg/l are stressful and may be lethal to many fish and other species

Dominant species - a plant species that exerts a controlling influence on or defines the character of a community

Downwelling - the process of build-up and sinking of surface waters along coastlines

Driving forces - the base drivers that play a large role in people's decision making processes and influence human behavior. Societal forces such as population, economy, technology, ideology, politics and social organizations are all drivers of environmental change.

Duration - a span or interval of time

Ebb - a period of fading away, low tide

Echinoderms - any of a phylum (Echinodermata) of radially symmetrical coelomate marine animals including the starfishes, sea urchins, and related forms

Economic impact analysis - used to estimate how changes in the flow of goods and services can affect an economy. Measure of the impact of dollars from outside a defined region/area on that region's economy. This method is often used in estimating the value of resource conservation.

Ecosystem - a topographic unit, a volume of land and air plus organic contents extended aerially for a certain time

Ecosystem services - the full range of goods and services provided by natural ecological systems that cumulatively function as fundamental life-support for the planet. The life-support functions performed by ecosystem services can be divided into two groups: production functions (i.e., goods) and processing and regulation functions (i.e., services).

Emergent plants - water plants with roots and part of the stem submerged below water level, but the rest of the plant is above water; e.g., cattails and bulrushes

Environmental equity - the perceived fairness in the distribution of environmental quality across groups of people with different characteristics

Environmental justice - a social movement focused on the perceived fairness in the distribution of environmental quality among people of different racial, ethnic or socio-economic groups

Ephemeral - lasting a very short time

Epifaunal - plants living on the surface of the sediment or other substrate such as debris

Epiphytes - plants that grow on another plant or object upon with it depends for mechanical support but not as a source of nutrients

Estuary - a part of a river, stream, or other body of water that has at least a seasonal connection with the open sea or Great Lakes and where the seawater or Great Lakes water mixes with the surface or subsurface water flow, regardless of the presence of man-made structures or obstructions.

Eukaryotic - organisms whose cells have a nucleus

Eulittoral - refers to that part of the shoreline that is situated between the highest and lowest seasonal water levels

Eutrophic - designating a body of water in which the increase of mineral and organic nutrients has reduced the dissolved oxygen, producing an environment that favors plant over animal life

Eutrophication - a natural process, that can be accelerated by human activities, whereby the concentration of nutrients in rivers, estuaries, and other bodies of water increases; over time this can result in anaerobic (lack of oxygen) conditions in the water column; the increase of nutrients stimulates algae "blooms; " as the algae decays and dies, the availability of dissolved oxygen is reduced; as a result, creatures living in the water accustomed to aerobic conditions perish

Evapotranspiration - a term that includes water discharged to the atmosphere as a result of evaporation from the soil and surface-water bodies and by plant transpiration

Existence value - the value that people place on simply knowing that something exists, even if they will never see it or use it

Exotic species - plants or animals not native to the area

Fauna - animals collectively, especially the animals of a particular region or time

Fecal coliforms - any of several bacilli, especially of the genera *Escherichia*, found in the intestines of animals. Their presence in water suggests contamination with sewage of feces, which in turn could mean that disease-causing bacteria or viruses are present. Fecal coliform bacteria are used to indicate possible sewage contamination. Fecal coliform bacteria are not harmful themselves, but indicate the possible presence of disease-causing bacteria, viruses, and protozoans that live in human and animal digestive systems. In addition to the possible health risks associated with them, the bacteria can also cause cloudy water, unpleasant odors, and increased biochemical oxygen demand.

Fetch - the distance along open water or land over which the wind blows

Fishery dependent data - data on fish biology, ecology and population dynamics that is collected in connection with commercial, recreational or subsistence fisheries.

Flooding regime - pattern of flooding over time

Floodplain - a strip of relatively flat land bordering a stream channel that may be overflowed at times of high water; the amount of land inundated during a flood is relative to the severity of a flood event

Flora - plants collectively, especially the plants of a particular region or time

Fluvial - of, relating to, or living in a stream or river

Focus group - a small group of people (usually 8 to 12) that are brought together by a moderator to discuss their opinions on a list of predetermined issues. Focus groups are designed to collect very detailed information on a limited number of topics.

Food chain - interrelations of organisms that feed upon each other, transferring energy and nutrients; typically solar energy is processed by plants who are eaten by herbivores which in turn are eaten by carnivores: sun –> grass –> mouse –> owl

Food webs - the combined food chains of a community or ecosystem

Frequency - how often something happens

Fronds - leaf-like structures of kelp plants

Function - refers to how wetlands and riparian areas work – the physical, chemical, and biological processes that occur in these settings, which are a result of their physical and biological structure

Functional habitat characteristics - characteristics that describe what ecological service a habitat provides to the ecosystem

Gastropods - any of a large class (Gastropoda) of mollusks (as snails and slugs) usually with a univalve shell or none and a distinct head bearing sensory organs

Geomorphic - pertaining to the form of the Earth or of its surface features

Geomorphology - the science that treats the general configuration of the Earth's surface; the description of landforms

Habitat - the sum total of all the living and non-living factors that surround and potentially influence an organism; a particular organism's environment

Hard bottom - the floor of a water body composed of solid, consolidated substrate, including reefs and banks. The solid floor typically provides an attachment surface for sessile organisms as well as a rough three-dimensional surface that encourages water mixing and nutrient cycling.

Hedonic pricing method - estimates economic values for ecosystem or environmental services that directly affect market prices of some other good. Most commonly applied to variations in housing prices that reflect the value of local environmental attributes.

Held values - conceptual precepts and ideals held by an individual about something. Natural resource examples include the symbolic value of a bald eagle or the aesthetic value of enjoying a beautiful sunset (see assigned values).

Herbivory - the act of feeding on plants

Holdfasts - a part by which a plant clings to a flat surface

Human dimensions - an multidisciplinary/interdisciplinary area of investigation which attempts to describe, predict, understand, and affect human thought and action toward natural environments in an effort to improve natural resource and environmental stewardship. Disciplines within human dimensions research is conducted include (but are not limited to) sociology, psychology, resource economics, geography, anthropology, and political science.

Human dominant values - this end of the natural resource value continuum emphasizes the use of natural resources to meet basic human needs. These are often described as utilitarian, materialistic, consumptive or economic in nature.

Human mutual values - the polar opposite of human dominant values, this end of the natural resource value continuum emphasizes spiritual, aesthetic, and nonconsumptive values in nature

Hydric soil - a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation; field indicators of hydric soils can include: a thick layer of decomposing plant material on the surface; the odor of rotten eggs; and colors of bluish–gray, gray, black, or sometimes gray with contrasting brighter spots of color

Hydrodynamics - the motion of water that generally corresponds to its capacity to do work such as transport sediments, erode soils, flush pore waters in sediments, fluctuate vertically, etc. Velocities can vary within each of three flow types: primarily vertical, primarily bidirectional and horizontal, and primarily unidirectional and horizontal. Vertical fluxes are driven by evapotranspiration and precipitation. Bidirectional flows are driven by astronomic tides and wind-driven seiches. Unidirectional flows are downslope movement that occurs from seepage slopes and floodplains.

Hydrogeomorphology - a branch of science (geology) that studies the movement of subsurface water through rocks, either as underground streams or percolating through porous rocks.

Hydrology - the study of the cycle of water movement on, over and through the earth's surface; the science dealing with the properties, distribution, and circulation of water

Hydroperiod - depth, duration, seasonality, and frequency of flooding

Hydrostatic pressure - the pressure water exerts at any given point when a body of water is in a still motion

Hypersaline - extremely saline, generally over 30 ppt salinity (average ocean water salinity)

Hypoxic - waters with dissolved oxygen less than 2 mg/L

IMPLAN - a micro-computer-based input-output (IO) modeling system (see Input-output model below). With IMPLAN, one can estimate 528 sector I-O models for any region consisting of one or more counties. IMPLAN includes procedures for generating multipliers and estimating impacts by applying final demand changes to the model.

Indirect impacts - the changes in sales, income or employment within the region in backward-linked industries supplying goods and services to tourism businesses. The increase in sales of linen supply firms that result from more motel sales is an indirect effect of visitor spending.

Induced impacts - the increased sales within the region from household spending of the income earned in tourism and supporting industries. Employees in tourism and supporting industries spend the income they earn from tourism on housing, utilities, groceries, and other consumer goods and services. This generates sales, income and employment throughout the region's economy.

Infauna - plants that live in the sediment

Informed consent - an ethical guideline for conducting social science research. Informed consent emphasizes the importance of both accurately informing research participants as to the nature of the research and obtaining their verbal or written consent to participate. The purpose, procedures, data collection methods and potential risks (both physical and psychological) should be clearly explained to participants without any deception.

Infralittoral - a sub-area of the sublittoral zone where upward-facing rocks are dominated by algae, mainly kelp

Input-output model (I-O) - an input-output model is a representation of the flows of economic activity between sectors within a region. The model captures what each business or sector must purchase from every other sector in order to produce a dollar's worth of goods or services. Using such a model, flows of economic activity associated with any change in spending may be traced either forwards (spending generating income which induces further spending) or backwards (visitor purchases of meals leads restaurants to purchase additional inputs -- groceries, utilities, etc.). Multipliers may be derived from an input-output models (see multipliers).

Instrumental values - the usefulness of something as a means to some desirable human end. Natural resource examples include economic and life support values associated with natural products and ecosystem functions (see non-instrumental values).

Intergenerational equity - the perceived fairness in the distribution of project costs and benefits across different generations, including future generations not born yet

Interstices - a space that intervenes between things; especially one between closely spaced things

Intertidal - alternately flooded and exposed by tides

Intrinsic values - values not assigned by humans but are inherent in the object or its relationship to other objects

Invasive species - a species that does not naturally occur in a specific area and whose introduction is likely to cause economic or environmental harm

Invertebrate - an animal with no backbone or spinal column; invertebrates include 95% of the animal kingdom

Irregularly exposed - refers to coastal wetlands with surface exposed by tides less often than daily

Lacunar - a small cavity, pit, or discontinuity

Lacustrine - pertaining to, produced by, or formed in a lake

Lagoons - a shallow stretch of seawater (or lake water) near or communicating with the sea (or lake) and partly or completely separated from it by a low, narrow, elongate strip of land

Large macroalgae - relatively shallow (less then 50 m deep) subtidal algal communities dominated by very large brown algae. Kelp and other large macroalgae grow on hard or consolidated substrates forming extensive three-dimensional structures that support numerous flora and fauna assemblages.

Large-scale commercial fishing - fishing fleets that are owned by corporations with large capital investments, and are highly mobile in their global pursuit of fish populations

Littoral - refers to the shallow water zone (less than 2 m deep) at the end of a marine water body, commonly seen in lakes or ponds

Longitudinal studies - social science research designed to permit observations over an extended period of time (see trend studies, cohort studies, and panel studies)

Macrofauna - animals that grow larger than 1 centimeter (e.g., animals exceeding 1 mm in length or sustained on a 1 mm or 0.5 mm sieve)

Macroinvertebrate - animals without backbones that can be seen with the naked eye (caught with a 1 mm^2 mesh net); includes insects, crayfish, snails, mussels, clams, fairy shrimp, etc

Macrophytes - plant species that are observed without the aid of an optical magnification e.g., vascular plants and algae

Mangroves - swamps dominated by shrubs that live between the sea and the land in areas that are inundated by tides. Mangroves thrive along protected shores with fine-grained sediments where the mean temperature during the coldest month is greater than 20º C, which limits their northern distribution.

Marine polyps - refer to the small living units of the coral that are responsible for secreting calcium carbonate maintaining coral reef shape

Market price method - estimates economic values for ecosystem products or services that are bought and sold in commercial markets

Marshes (marine and freshwater) - coastal marshes are transitional habitats between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water tidally or seasonally. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Mast - the nuts of forest trees accumulated on the ground

Measurement error - a type of survey error that occurs when a respondent's answer to a given question is inaccurate, imprecise, or cannot be compared to other respondent's answers

Meiofauna - diverse microorganisms that are approximately between .042 mm and 1 mm in size

Meristematic - the ability to form new cells that separate to form new tissues

Mesocosm - experimental tanks allowing studies to be performed on a smaller scale

Metadata - data that describes or provides background information on other data

Microfauna - animals that are very small and best identified with the use of a microscope, such organisms include protozoans and nematodes

Microinvertebrates - invertebrate animals that are so small they can only be observed with a microscope

Micro-topography - very slight changes in the configuration of a surface including its relief and the position of its natural and man-made features

Migratory - a creature that moves from one region to another when the seasons change

Morphology - the study of structure and form, either of biological organisms or features of the earth surface

Mottling - contrasting spots of bright colors in a soil; an indication of some oxidation or ground water level fluctuation

Mudflat - bare, flat bottoms of lakes, rivers and ponds, or coastal waters, largely filled with organic deposits, freshly exposed by a lowering of the water level; a broad expanse of muddy substrate commonly occurring in estuaries and bays

Multipliers - capture the size of the secondary effects in a given region, generally as a ratio of the total change in economic activity in the region relative to the direct change. Multipliers may be expressed as ratios of sales, income or employment, or as ratios of total income or employment changes relative to direct sales. Multipliers express the degree of interdependency between sectors in a region's economy and therefore vary considerably across regions and sectors

Nanoplankton - plankton of minute size, generally size range is from 2 to 20 micrometers

Native - an animal or plant that lives or grows naturally in a certain region

Nearshore - nearshore waters begin at the shoreline or the lakeward edge of the coastal wetlands and extend offshore to the deepest lakebed depth contour, where the thermocline typically intersects with the lake bed in late summer or early fall

Nekton - free-swimming aquatic animals (such as fish) essentially independent of wave and current action

Non-instrumental values - something that is valued for what it is; a good of its own; an end in itself. Natural resource examples include aesthetic and spiritual values found in nature (see instrumental values)

Non-market goods and services - goods and services for which no traditional market exists whereby suppliers and consumers come together and agree on a price. Many ecosystem services and environmental values fall under this category

Non-point source - a source (of any water–carried material) from a broad area, rather than from discrete points

Nonresponse error - a type of survey error that occurs when a significant proportion of the survey sample do not respond to the questionnaire and are different from those who do in a way that is important to the study

Non-use values - also called “passive use” values, or values that are not associated with actual use, or even the option to use a good or service

Norms - perceived standards of acceptable attitudes and behaviors held by a society (social norms) or by an individual (personal norms). Serve as guideposts for what is appropriate behavior in a specific situation.

Nuisance species - undesirable plants and animals, commonly exotic species

Null hypothesis - a statement about the values of one or more parameters usually describing a condition of no change or difference

Nutria - a large South American semiaquatic rodent (*Myocastor coypus*) with webbed hind feet that has been introduced into parts of Europe, Asia, and North America

Nutrient - any inorganic or organic compound that provides the nourishment needed for the survival of an organism

Nutrient cycling - the transformation of nutrients from one chemical form to another by physical, chemical, and biological processes as they are transferred from one trophic level to another and returned to the abiotic environment

Octocorals - corals with eight tentacles on each polyp. There are many different forms that may be soft, leathery, or even those producing hard skeletons.

Oligohaline - an area of an estuary with salinities between 0.5 and 5.0 ppt

Oligotrophic - a water body that is poor in nutrients. This refers mainly to lakes and ponds

One-hundred year flood - refers to the floodwater levels that would occur once in 100 years, or as a 1.0 percent probability per year

Opportunity cost - the cost incurred when an economic decision is made. This cost is equal to the benefit of the most highly valued alternative that would have been gained if a different decision had been made. For example, if a consumer has $2.00 and decides to purchase a sandwich, the economic cost may be that consumer can no longer use that money to buy fruit.

Option value - the value associated with having the option or opportunity to benefit from some resource in the future

Organic - containing carbon, but possibly also containing hydrogen, oxygen, chlorine, nitrogen, and other elements

Organic material - anything that is living or was living; in soil it is usually made up of nuts, leaves, twigs, bark, etc.

Osmotic stress - water stresses due to differences in salinity between an organism and its aquatic environment

Outdoor recreation conflict - defined as behavior of an individual or group that is incompatible with the social, psychological or physical goals of another person or group

Oyster beds - dense, highly structured communities of individual oysters growing on the shells of dead oysters

Panel studies - longitudinal research that studies the same set of people through time in order to investigate changes in individuals over time (see longitudinal studies)

Pelagic - pertaining to, or living in open water column

Personal area network (PAN) - a computer network used for communicating between computer devices (including telephones and personal digital assistants) and a person

Petiole - the stalk of a leaf, attaching it to the stem

pH - a measure of the acidity (less than 7) or alkalinity (greater than 7) of a solution; a pH of 7 is considered neutral

Phenology - refers to the life stages a plant/algae experiences (e.g., shoot development in kelp)

Physiographic setting - the location in a landscape, such as stream headwater locations, valley bottom depression, and coastal position. Similar to geomorphic setting.

Physiography - a description of the surface features of the Earth, with an emphasis on the mode or origin

Phytoplanktivores - animals that eat planktonic small algae that flow in the water column

Phytoplankton - microscopic floating plants, mainly algae that are suspended in water bodies and are transported by wave currents because they cannot move by themselves swim effectively against a current.

Piscivorous - feeding on fish

Planktivorous - eating primarily plankton

Plankton - plant and animal organisms, generally microscopic, that float or drift in water

Pneumatocysts - known as gas bladders or floaters that help the plant stay afloat such as the bladders seen in the brown alga *Macrocystis*

Pneumatophores - specialized roots formed on several species of plants occurring frequently in inundated habitats; root is erect and protrudes above the soil surface

Polychaete - a group of chiefly marine annelid worms armed with setae, or bristles, extending from most body segments

Population - a collection of individuals of one species or mixed species making up the residents of a prescribed area

Population list - in social science survey research, this is the list from which the sample is drawn. This list should be as complete and accurate as possible and should closely reflect the target population.

ppt - parts per thousand. The salinity of ocean water is approximately 35 ppt

Precision - a statistical term that refers to the reproducibility of the result or measurement. Precision is measured by uncertainty and is usually expressed as the standard error or some confidence interval around the estimated mean.

Prop roots - long root structures that extend midway from the trunk and arch downward creating tangled branching roots above and below the water's surface, such as the mangrove *Rhizophora*

Propagules - a structure (cutting, seed, spore, rhizome, etc.) that causes the continuation or increase of a plant, by sexual or asexual reproduction

Protodeltaic - similar in form to the early stages of delta formation

Pseudofeces - material expelled by the oyster without having gone through the animal's digestive system

Quadrats - are rectangular, or square shaped instruments used to estimate density, cover and biomass of both plants and animals

Quality assurance/quality control plan - a detailed plan that describes the means of data collection, handling, formatting, storage, and public accessibility for a project

Random utility models - a non-market valuation technique that focuses on the choices or preferences of recreationists among alternative recreational sites. Particularly appropriate when substitutes are available to the individual so that the economist is measuring the value of the quality characteristics of one or more site alternatives (e.g., a fully restored coastal wetland and a degraded coastal wetland).

Receiving water bodies - lakes, estuaries, or other surface waters that have flowing water delivered to them

Recruitment - the process of adding new individuals to a population or subpopulation (as of breeding individuals) by growth, reproduction, immigration, and stocking; also a measure (as in numbers or biomass) of recruitment

Redox potential - oxidation-reduction potential; often used to quantify the degree of electrochemical reduction of wetland soils under anoxic conditions

Reference condition - set of selected measurements or conditions of minimally impaired waterbodies characteristic of a waterbody type in a region

Reference site - a minimally impaired site that is representative of the expected ecological conditions and integrity of other sites of the same type and region

Reflectance - The ratio of the light that radiates onto a surface to the amount that is reflected back

Regime - a regular pattern of occurrence or action

Reliability - the likelihood that a given measurement procedure or technique will yield the same result each time that measure is repeated (i.e., reproducibility of the result) (see Precision)

Remote sensing - the process of detecting and monitoring physical characteristics of an area by measuring its reflected and emitted radiation and without physically contacting the object

Restoration - the process of reestablishing a self-sustaining habitat that in time can come to closely resemble a natural condition in terms of structure and function

Restoration monitoring - the systematic collection and analysis of data that provides information useful for measuring restoration project performance at a variety of scales (locally, regionally, and nationally)

Rhizome - somewhat elongate usually horizontal subterranean plant stem that is often thickened by deposits of reserve food material, produces shoots above and roots below, and is distinguished from a true root in possessing buds, nodes, and usually scale-like leaves

Riparian - a form of wetland transition between permanently saturated wetlands and upland areas. These areas exhibit vegetation or physical characteristics reflective of permanent surface of subsurface water influence. Lands along, adjacent to, or contiguous with perennially and intermittently flowing rivers and streams, glacial potholes, and the shores of lakes and reservoirs with stable water levels are typically riparian areas. Excluded are such sites as ephemeral streams or washes that do not exhibit the presence of vegetation dependent upon free water in the soil.

Riverine - of, or associated with rivers

Riverine forests - forests found along sluggish streams, drainage depressions, and in large alluvial floodplains. Although associated with deepwater swamps in the SE United States, riverine forests are found throughout the US and do not exhibit prolonged flooding.

Rocky shoreline - extensive hard bottom littoral habitats on wave-exposed coasts

RVD (recreational visitor day) - one RVD is defined as 12 hours of use in some recreational activity. This could be one person using an area for 12 hours, or 2 people using an area for 6 hours each, or any combination of people and time adding to 12 hours of use.

Salinity - the concentration of dissolved salts in a body of water; commonly expressed as parts per thousand

Salt pans - an undrained natural depression in which water gathers and leaves a deposit of salt on evaporation

Sample - in social science survey research, this is a set of respondents selected from a larger population for the purpose of a survey

Sampling designs - the procedure for selecting samples from a population and the subsequent statistical analysis

Sampling error - a potential source of survey error that can occur when researchers survey only a subset or sample of all people in the population instead of conducting a census. To minimize this error the sample should be as representative of the population as possible.

Satisfaction - in outdoor recreation, satisfaction is defined as the difference between desired and achieved goals. Can be measured through surveys of recreation participants.

SAV (submerged aquatic vegetation) - marine, brackish, and freshwater submerged aquatic vegetation that grows on soft sediments in sheltered shallow waters of estuaries, bays, lagoons, and lakes

Seasonality - the change in naturally cycles, such as lunar cycles and flooding cycles, from one season to the next

Secondary data - information that has already been assembled, having been collected for some other purpose. Sources include census reports, state and federal agency data, and university research.

Secondary effects - the changes in economic activity from subsequent rounds of re-spending of tourism dollars. There are two types of secondary effects: indirect effects and induced effects.

Sector - a grouping of industries that produce similar products or services. Most economic reporting and models in the U.S. are based on the Standard Industrial Classification system (SIC code). Tourism is more an activity or type of customer than an industrial sector. While hotels (SIC 70) are a relatively pure tourism sector, restaurants, retail establishments and amusements sell to both tourists and local customers. There is therefore no simple way to identify tourism sales in the existing economic reporting systems, which is why visitor surveys are required to estimate tourist spending.

Sediment porewater - water in the spaces between individual grains of sediment

Seiches - a sudden oscillation of the water in a moderate-size body of water, caused by wind

Seine - a net weighted at the bottom with floats at the top so it remains vertical in the water. A seine can be towed behind a boat or smaller versions, attached to poles, may be operated by hand.

Senescence - the growth phase in a plant or plant part (as a leaf) from full maturity to death, also applies to winter dormancy

Sessile - plants that are permanently attached or established; animals that do not freely move about

Simple random sampling (SRS) - in survey research, when each member of the target population has an equal change of being selected. If a population list exists, SRS can be achieved using a computer-generated random numbers.

Small-scale commercial fishing - fishing operations that have relatively small capital investment and levels of production, and are more limited in terms of mobility and resource options (compared to large-scale operations). Terms that are commonly used to describe small-scale fishermen include native, coastal, inshore, tribal, peasant, artisanal, and traditional.

Social capital - describes the internal social and cultural coherence of society, the norms and values that govern interactions among people and the institutions in which they are embedded

Social impact assessment (SIA) - analysis conducted to assess, in advance, the social consequences that are likely to follow from specific policy actions and alternatives. Social impacts in this context refers to the consequences to human populations that alter the ways in which people live, work, play, relate to one another, organize and generally cope as members of society.

Social network mapping - community assessment research method used to collect, analyze, and graphically represent data that describe patterns of communication and relationships within a community

Socioeconomic monitoring - tracking of key indicators that characterize the economic and social state of a community

Soft bottom - loose, unconsolidated substrate characterized by fine to coarse-grained sediment

Soft shoreline - sand beaches, dunes, and muddy shores. Sandy beaches are stretches of land covered by loose material (sand), exposed to and shaped by waves and wind.

Stakeholders - individuals, groups, or sectors that have a direct interest in and/or are impacted by the use and management of natural resources in a particular area, or that have responsibility for management of those resources

Statistical protocol - a method of a analyzing a collection of observed values to make an inference about one or more characteristic of a population or unit

Strands - a diffuse freshwater stream flowing through a shallow vegetated depression on a gentle slope

Structural habitat characteristics - characteristics that define the physical composition of a habitat

Subsistence - describes the customary and traditional uses of renewable resources (i.e., food, shelter, clothing, fuel) for direct personal/family consumption, sharing with other community members, or for barter. Subsistence communities are often held together by patterns of natural resource production, distribution, exchange, and consumption that helps maintain a complex web of social relations involving authority, respect, wealth, obligation, status, power and security.

Subtidal - continuously submerged; an area affected by ocean tides

Supralittoral region - is that area which is above the high tide mark receiving splashing from waves

Target population - the subset of people who are the focus of a survey research project

Taxa - a grouping of organisms given a formal taxonomic name such as species, genus, family, etc. (singular form is taxon)

Temporal - over time

Thermocline - the region in a thermally stratified body of water which separates warmer oxygen-rich surface water from cold oxygen-poor deep water and in which temperature decreases rapidly with depth

Tide - the rhythmic, alternate rise and fall of the surface (or water level) of the ocean, and connected bodies of water, occurring twice a day over most of the Earth, resulting from the gravitational attraction of the Moon, and to a lesser degree, the Sun

Topography - the general configuration of a land surface or any part of the Earth's surface, including its relief and the position of its natural and man–made features

Transect - two types of transects, point and line. Point intercept transect methods is performed by placing a point frame along a set of transect lines. Line transects are when a line is extended from one point to the next within the designated sample area

Transient - passing through or by a place with only a brief stay or sojourn

Transit - a surveying instrument for measuring horizontal and vertical angles; appropriate to help determine actual location of whale surfacing. It contains a small telescope that is placed on top of a tripod.

Travel cost method (TCM) - TCM is used to estimate monetary value of a geographical site in its current condition (i.e., environmental health, recreational use capacity, etc.) by site-users. Individuals or groups report travel-related expenditures made while on trips to single and multiple recreational sites. Market values are used.

Trend studies - longitudinal research that studies changes within some general population over time (see longitudinal studies)

Trophic - refers to food, nutrition, or growth state

Trophic level - a group of organisms united by obtaining their energy from the same part of the food web of a biological community

Turf - cover (the ground) with a surface layer of grass or grass roots

Unconsolidated - loosely arranged

Utilitarian value - valuing some object for its usefulness in meeting certain basic human needs (e.g., food, shelter, clothing). Also see human-dominant values

Validity - refers to how close to a true or accepted value a measurement lies

Vibracore - refers to a high frequency, low amplitude vibration, coring technique used for collecting sediment samples without disrobing the sample

Viviparous - producing living young instead of eggs from within the body in the manner of nearly all mammals, many reptiles, and a few fishes; germinating while still attached to the parent plant

Water column - a conceptual volume of water extending from the water surface down to, but not including the substrate. It is found in marine, estuarine, river, and lacustrine systems.

Watershed - surface drainage area that contributes water to a lake, river, or other body of water; the land area drained by a river or stream

Willingness-to-pay - the amount in goods, services, or dollars that a person is willing to give up to get a particular good or service

Zonation - a state or condition that is marked with bands of color, texture, or plant species

Zooplanktivorus - animals that feed upon zooplankton

Zooplankton - free-floating animals that drift in the water, range from microscopic organisms to larger animals such as jellyfish

References

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